Critical infrastructure impacts and adaptations in small rural towns following the 2016 Kaikōura earthquake, New Zealand.

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by

Damon James McKibbin

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Department of Geological Sciences
University of Canterbury
New Zealand

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Abstract

On 14 November 2016, the Mw 7.8 Kaikōura earthquake caused widespread damage along the east coast of the South Island, New Zealand. Kaikōura town itself was isolated from the rest of the country by landslides blocking off major roads. While impacts from the Kaikōura earthquake on large, urban population centres have been generally well documented, this thesis aims to fill gaps in academic knowledge regarding small rural towns. This thesis investigates what, where and when critical infrastructure and lifeline service disruption occurred following the 2016 Kaikōura earthquake in a selection of small towns, and how the communities in these areas adapted to disruption. Following a robust review of literature and news media, four small rural towns were selected from North Canterbury (Culverden & Waiau) and Marlborough (Seddon & Ward) in the South Island, New Zealand. Semi-structured interview sessions with a special focus on these towns were held with infrastructure managers, emergency response and recovery officials, and organisation leaders with experience or expertise in the 2016 Kaikōura earthquake. Findings were supplemented with emergency management situation reports to produce hazard maps and infrastructure exposure maps. A more detailed analysis was conducted for Waiau involving interdependence analyses and a level of service timeline for select lifeline services. The earthquake impacted roads by blocking them with landslides, debris and surface rupture. Bridges where shaken off their abutments, breaking infrastructure links such as fibre landlines as they went. Water supplies and other forms of infrastructure relied heavily on the level of service of roads, as rough rural terrain left few alternatives. Adapting to an artificial loss of road service, some Waiau locals created their own detour around a road cordon in order to get home to family and farms. Performance of dwellings was tied to socioeconomic factors as much as proximity to the epicentre. Farmers who lost water access pulled out fences to allow stock to drink from rivers. Socioeconomic differences between farmland and township residents also contributed to resilience variations between the towns assessed in this study. Understanding how small rural towns respond and adapt to disaster allows emergency management officials and policy to be well informed and flexible with planning for multiple size classes of towns.

Acknowledgements

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Abbreviations

GIS – Geographic Information System

MMI – Modified Mercalli Intensity

GXP – Grid exit point

LINZ – Land Information New Zealand

MDC – Marlborough District Council

HDC – Hurunui District Council

NCTIR – North Canterbury Transport Infrastructure Recovery [Alliance]

ECan – Environment Canterbury

AC – Asbestos cement

DOC – Department of Conservation

CDEM [Group] – Civil Defence and Emergency Management Group

MBIE – Ministry of Business, Innovation and Employment

SH[X] – State Highway [X]

PTSD – Post Traumatic Stress Disorder

CIMS – Coordinated Incident Management System

NZTA – NZ Transport Agency

KDC – Kaikōura District Council

PHO – Primary Health Organisation

MIOX – Mixed oxidant solution

ARI – Average return interval

LOS – Level of service

KEAR – Kaikōura Emergency Access Route

Chapter 1: Introduction

1.1 Background

On 14 November 2016, a M_w 7.8 earthquake occurred 95 km north-east of Christchurch (11 km south of Waiau) and 15 km deep (GeoNet, 2016). This earthquake was the latest in a series of high-profile earthquakes to hit the Canterbury and Marlborough regions within the previous decade (Table 1.1). This includes the 2010 Darfield and 2011 Christchurch earthquakes which caused severe damage in the city of Christchurch, displacing thousands (Newell, et al., 2012). One distinguishing aspect of the 2016 Kaikōura earthquake from these two events in particular is that it occurred relatively far from densely populated areas. The small, rural settlements and coastal towns in North Canterbury and South Marlborough experienced substantial physical damage and social and economic impacts. The physical damage was dramatic with arterial roads buried in landslides (Villeneuve, et al., 2017), critical infrastructure severed by fault rupture (GeoNet, 2016), hundreds of structures moderately to severely damaged by ground shaking (Dizhur, et al., 2017), and coastal displacement of up to 6.5 m in places due to uplift (GeoNet, 2016). The Kaikōura earthquake comprised of a complex rupture pattern, activating a series of faults, which ruptured in a northeast direction over time (Bradley, et al., 2017).

Table 1.1: Recent earthquakes affecting the study area

Common Name	Date	Magnitude (Mw)	Depth (km)
2010 Canterbury (Darfield) Earthquake	3 September 2010	7.2	11
2011 Christchurch Earthquake	21 February 2011	6.2	5.4
2013 Seddon Earthquake	21 July 2013	6.5	15.6
2013 Lake Grassmere Earthquake	16 August 2013	6.5	7.5
2016 Kaikōura Earthquake	14 November 2016	7.8	15

The purpose of this Master of Science project is to investigate what, where and when critical infrastructure and lifeline service disruption occurred following the Kaikōura earthquake in a selection of small towns, and how the communities in these areas adapted to disruption. As

New Zealand is prone to a range of extreme natural hazard events, the information gathered will help inform resilience measures for future periods of service disruption in rural and remote areas. Our research into four small rural towns (Figure 1.1) is guided by these key objectives:

- Document the critical infrastructure impacts on small towns in North Canterbury and Marlborough
- Examine anticipated and actual adaptations to lifeline service disruption
- Assess the success of these adaptations, and consider the implications of future changes to infrastructure and environment

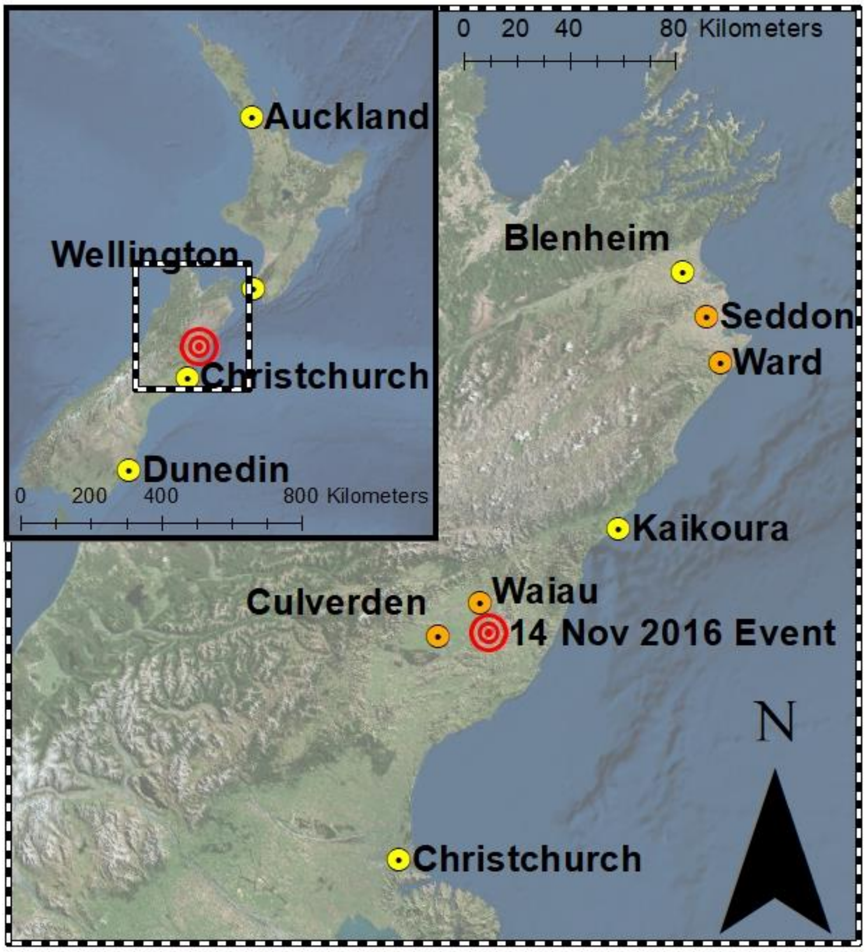


Figure 1.1: Distribution of case study towns in orange, major non-study towns in yellow and the epicentre of the 'Kaikōura' Earthquake

1.2 Risk Management

1.2.1 Sendai Framework

The Sendai Framework for Disaster Risk Reduction is a global disaster resilience plan endorsed by The United Nations International Strategy for Disaster Reduction (UNISDR). As a voluntary, non-binding 15-year plan, UN member countries may sign and follow the agreement to prevent new and reduce existing disaster risk (UNISDR, 2015). This is accomplished through a multidisciplinary, integrated approach (UNISDR, 2015). New Zealand is a signatory to the Sendai Framework for Disaster Risk Reduction, which has informed Civil Defence and Emergency Management's (CDEM) 2015 National Plan and is guiding the development of the National Disaster Resilience Strategy - in turn regulating risk reduction and resilience measures at a regional level (New Zealand Government, 2015). This project closely aligns with the four Priorities for Action proposed in the Sendai Framework by:

1. Assisting to understand disaster risk by reviewing where, when and how critical infrastructure was damaged or services were disrupted.
2. Strengthening disaster risk governance by communicating our findings with local government and CDEM administration.
3. Identifying targets for active investment in disaster risk reduction for resilience by investigating key infrastructure failures.
4. Enhancing future disaster preparedness and recovery rehabilitation and reconstruction through the knowledge gained from literature and interviews with affected communities (UNISDR, 2015).

Several conceptual models have been produced to describe the relationships between natural hazards and risk. The exact equations and definitions differ between various authors (UNISDR, 2017; Koks, et al., 2015), however the core principle tends to remain the same. For this project we adopt the equation used by the United Nations International Strategy for Disaster Reduction (UNISDR). Their concept is as follows:

$$(\mathbf{H} \times \mathbf{V} \times \mathbf{E}) / \mathbf{R} = \mathbf{Dr}$$

Where **H** is the Hazard itself, **V** is the Vulnerability of a community and **E** is Exposure of a community to the hazard. These three inputs amplify one another, however if any value is zero then the value for **Dr**, Disaster Risk, is also zero. Unlike Koks, et al. (2015), UNISDRs equation adds the input **R** for Resilience, which acts as a mitigating factor on **H**, **V** and **E**. Resilience includes such things as an educated and aware populace, sensible building codes and the physical ability to respond to disasters (UNISDR, 2017). We consider R as we will be investigating adaptations made by the community, a form of resilience.

1.2.2 Hazard Management

Hazard impact assessments are crucial to efficient policymaking. Impact analyses improve crisis management through empowering decision-makers in resilience planning, by presenting accurate, up to date information on hazard consequences (Laugé, et al., 2013). These consequences mainly fall into social (Maguire & Cartwright, 2008), health, economic and environmental spheres (Hinrichs, et al., 2011), which may be assessed individually or holistically as required (Laugé, et al., 2013). The latter may be further separated into natural and built environments where applicable (Hinrichs, et al., 2011).

Earthquakes may generate a number of primary and secondary hazards. Primary hazards are intrinsic to the initial event, while secondary hazards are generated by the interaction of primary hazards with infrastructure and the environment (Marano, et al., 2010). For example, a primary hazard such as ground-shaking can trigger the secondary hazard of landslides through interaction with steep, unstable and/or saturated slopes in the environment. Varying earthquake magnitudes and shaking intensities, environmental conditions and human exposure can result in inconsistent generation of hazards between events, and some hazards may not develop at all given certain geographical and environmental conditions (Marano, et al., 2010). Reported primary and secondary hazards of the 2016 Kaikōura earthquake will be addressed later in this review.

1.2.3 Acceptable Risk and ‘ALARP’

Zero risk is impossible (Rovins, et al., 2015). Acceptable risk is defined as potential losses a community considers acceptable and is governed by societal norms, politics, economics and physical barriers to resilience (Rovins, et al., 2015). This incompletely describes risk entertained by a community, which falls under tolerable risk (Rovins, et al., 2015).

Intolerable or unacceptable risk is outside the consent of a community altogether (Rovins, et al., 2015).

As Low As Reasonably Possible/Practicable (ALARP) refers to risk which is as low as practically feasible, a risk reduction threshold entities are ethically responsible for reaching (Parkes, 2017). This principle is also way of justifying tolerable risk under practical circumstances, as it recognises that beyond a certain point further risk reduction is increasingly costly (Jones-Lee & Aven, 2011). The investment of time and resources can become disproportionate to the risk negated when risk is sufficiently reduced (Jones-Lee & Aven, 2011). There is no worldwide standard for tolerable risk limits, which themselves vary by risk context (Parkes, 2017). This exacerbates differences in perception of risk between the public and even different levels of required hazard management, and was demonstrated following the Kaikōura earthquake, as detailed later in this thesis. Figure 1.2 illustrates these concepts.

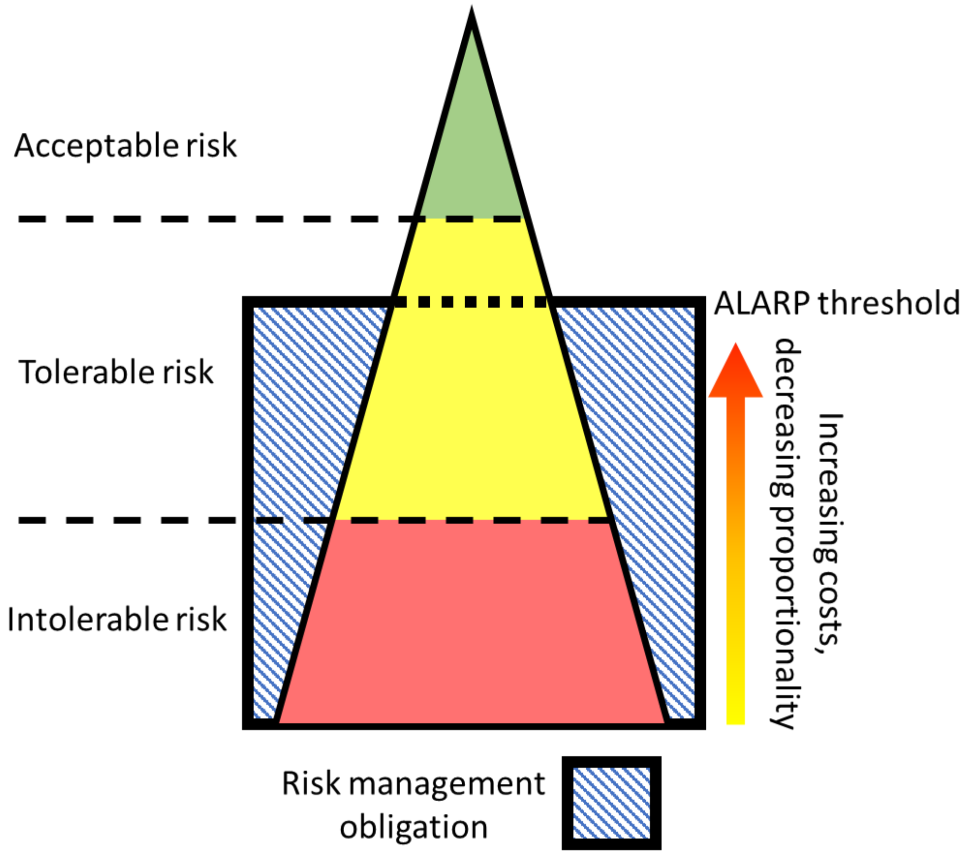


Figure 1.2: Acceptable, Tolerable and Intolerable Risk with ALARP threshold. Adapted from Sofyalloglu et al., 2017.

1.2.4 Prioritisation of Lifelines

It is the responsibility of MCDEM (Ministry of Civil Defence & Emergency Management) and CDEM groups to identify and resolve emerging conflicts in the prioritisation of restoring disrupted lifeline services as part of their coordination efforts (MCDEM, 2015). The service disruptions themselves are triaged according to a scale ranging from local, to regional, to national significance. A disruption of local significance would fall under the jurisdiction of a single territorial authority and CDEM Group (MCDEM, 2015). Where two or more territorial authorities are affected, the situation is upgraded to regional significance (MCDEM, 2015). The Civil Defence Emergency Management Act (2002) defines national significance as involving any

- Widespread public concern or interest
- Likely significant use of resources
- Jurisdiction of two or more CDEM groups
- Likely impact on New Zealand's international obligations
- Likely involvement of technologies, processes or methods new to New Zealand
- Likely to result in or contribute to significant or irreversible changes to the environment, both domestic and global.

Some organisations prefer a population-based approach to critical infrastructure and lifeline service significance, where set thresholds of affected individuals determine ranking (Canterbury Lifeline Utilites Group, 2018), however this is difficult to estimate accurately in remote rural localities and is not what is supported in legislation (CDEM Act, 2002). This is because seasonal and year to year numbers for tourism and itinerant workers are constantly fluctuating. Raw population estimates also struggle to take into account population density and remoteness (Gerald, 2016), further complicating this. It is possible for disruptions of local or regional significance to inherit higher classifications based on the interdependency of services and infrastructure. For example, the failure of powerlines along an isthmus may be traditionally considered as locally significant if it occurs within a single territorial authority. However if these particular lines were responsible for powering a water treatment facility, which is considered of national significance, the powerlines inherit the significance of the water treatment facility (MCDEM, 2015). Such scenarios have intersectional importance with many communities in the South Island of New Zealand where local infrastructure failure can have repercussions on regional and national scales. Following this logic, localised adaptations to service disruption may also have the potential to impact other communities.

1.3 Small towns and critical infrastructure

Small towns face a number of challenges specific to their population size. Low populations generally result in a limited tax base and low reinvestment within the local community, restricting funds for the upkeep of local infrastructure (Howard, 2015). Self-sufficiency is more difficult for geographically remote[1] towns than for major population centres. This is because the economics often do not justify maintaining infrastructure to facilities or networks that cater to only a few remote households, especially over difficult terrain (Gerald, 2016; Howard, 2015). Facilities that people take for granted in larger population centres, such as supermarkets and schools, are more sparsely distributed in low population density regions (Gerald, 2016). In many cases, small towns in high-income countries are progressively affected by stagnant or declining populations which puts further strain on the ability for local government to fund the ever-increasing costs of infrastructure maintenance and restoration (Wood, 2017; Howard, 2015), particularly with comparatively high population growth rates in cities. For example, Ruapehu District in the central North Island of New Zealand, recently reported it must source >NZ$1 million for a new water treatment plant that services only 9,000 people (Wilson, et al., 2017). We therefore see interdependence forming between small communities, or satellite settlements that rely on a larger nexus. This may result in long commutes for goods and services, which become lengthier should local options be disrupted (Gerald, 2016). The concept of interdependencies between communities like this is of interest as it highlights the importance of restoring specific service routes, such as road blockages isolating one community from another with a supermarket.

[1] We clarify our definitions of the terms *remote* and *isolated* as follows because the use of the words is often inconsistent in literature (Gerald, 2016; New Zealand Government, 2015): We refer to isolated communities as those that have been disconnected or separated from other communities or administration through the disruption of infrastructure, services or lifeline utilities. Examples of disruption include landslides blocking main roads and electricity failure from power lines broken by severe ground shaking. We refer to remote communities as those that are distant or physically difficult to access.

Lifeline utilities are defined by CDEM as entities and operators that provide essential lifeline services, such as transport, water, power and communications (Waikato Lifeline Utilities Group, 2017). These are supported by physical critical infrastructure which includes roads, water pipes, power lines and cell towers. The vulnerability of critical infrastructure is therefore of considerable interest to disaster resilience planners. As discussed previously, small town infrastructure is considered to be more vulnerable to hazards as there is less money available for regular maintenance and development (Gerald, 2016). This situation is exacerbated in remote localities, where access to maintain and repair infrastructure may not be ideal. Population size, therefore, will be an important filter in our selection of study sites. Compounding issues of low population and the rugged terrain of New Zealand increases costs to maintain and develop infrastructure (NIU, 2015) – further limiting options for redundancies. Public and administrative awareness of critical infrastructure has implications for adaptability and disaster resilience (Giovinazzi, et al., 2017; GNS Science, 2013), which is another aspect to be explored. A diverse range of primary industries are important employers for people living in rural areas (Stats NZ, n.d. a).

1.4 Kaikōura Earthquake

The 2016 Kaikōura earthquake triggered several primary and secondary hazards (GeoNet, 2016). Primary hazards included shaking and surface rupture, which developed landslides, liquefaction and tsunami (Figure 1.3). In Chapter 3 I discuss the particular impacts these hazards had on exposed infrastructure.

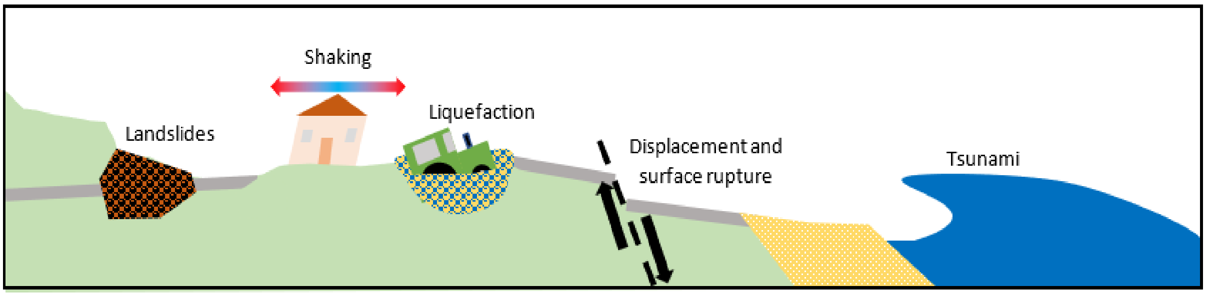


Figure 1.3: Visualisation of earthquake hazards applicable to the 2016 Kaikōura earthquake context.

1.4.1 Hazards

1.4.1.1 Strong Ground Motion

As arguably the most well-known primary hazard of earthquakes, the effects of ground shaking sit at the forefront of urban damage investigation. Bradley et al. (2017) gives specific attention to near-source shaking during the earthquake, which saw ground motion exceeding 1.0g horizontally and 2.7g vertically in one location. Ground motion was strongest in and around the Kaikōura District (Bradley, et al., 2017).

Figure 1.4: Papatea Fault surface rupture across SH1 (Stirling et al., 2017).

1.4.1.2 Surface Rupture

More than 30 km of surface rupture has been observed in satellite imagery, with up to 12 m of strike-slip displacement (Hollingsworth, et al., 2017). Surface rupturing has the potential for serious infrastructure disruption (Hollingsworth, et al., 2017), as seen with segments of road and railway which suffered from severe deformation (Figure 1.4)(NCTIR, 2017a).

1.4.1.3 Landslides

Shaking also triggered tens of thousands of landslides in the Canterbury and Marlborough regions, covering roads and rail (Davies, et al., 2017; Massey & Dellow, 2017; NCTIR, 2017b; Villeneuve, et al., 2017). Figure 1.5 depicts one of many such landslides along SH1, which was strong enough to push train tracks from the foot of the cliff, across the road onto the beach. Landslides along rivers were also common, with many creating earth dams (Little, 2016). Large volumes of water would build up behind them until structural failure releases flash flooding into the river valley. As of February 2019, seismogenic landslide totals are still being tallied, through such techniques as satellite imagery analysis, fieldwork and aerial photography investigation (Rosser, et al., 2017).

Figure 1.5: Landslide blocking SH1 and pushing Main North Line train tracks off the railroad (Steve Murrin, 2016).

1.4.1.4 Liquefaction

Liquefaction damage from the Kaikōura earthquake was low, relative to the 2011 Canterbury earthquakes. This is largely due to the hilly, draining geomorphology of the North Canterbury and Marlborough regions (Smith, 2016). Although liquefaction was uncommon within the study area, damage to the reclaimed land of Wellington centreport was significant (Cubrinovski, et al., 2017).

1.4.1.5 Tsunami

The tsunami accompanying the 2016 Kaikōura earthquake was generated under unusual conditions. The earthquake began on land and propagated offshore – activating multiple faults along the sea floor (Bai, et al., 2017). Before the complex nature of the earthquake was uncovered, it was assumed from the initial epicentre reports that it was sufficiently inland to not cause a tsunami (Borrero & Lane, 2018) and a 'National Advisory: No Tsunami Threat' message was issued 38 minutes after the earthquake (MCDEM, 2017a). Just as this message was issued tide gauges observed a sudden drop in sea level consistent with tsunami generation and a 'National Warning: Tsunami Threat' was issued 20 minutes later (MCDEM, 2017a). Bai, et al. (2017) used computer modelling to simulate the contribution these faults may have on tsunami generation, finding that two regions of seafloor motion produced the tsunami. The tsunami left a ~4 m crest-to-trough signal at Kaikōura (Bai, et al., 2017) and a run-up as high as 6.9 m at Goose Bay, south of Kaikōura (Power, et al., 2017). As the tsunami arrived at the shoreline around mid to low tide, the damage was minimal (GeoNet, 2016).

1.4.1.6 Evacuations

Exposure to human life was also minimised due to widespread self-evacuation following the earthquake (GeoNet, 2017). Some of this self-evacuation was excessive however, as people several kilometres outside of evacuation zones congested roads leading out of coastal communities (Schoenfeld, 2018). Substantial confusion over whether or not to evacuate arose out of inconsistencies between MCDEM and local CDEM messages – when MCDEM gave instruction to evacuate, local CDEM would not activate tsunami warning sirens in many cases (Schoenfeld, 2018).

1.4.1.7 Rain events

Multiple heavy rain events occurred in November and December 2016 following the earthquake, further activating landslides and washing away loosened topsoil. These environmental impacts were most evident in the Marlborough Sounds. Heavy rain continues to be an issue for erosion management along the cliff face overlooking SH1.

1.4.2 Social Considerations

Damage to property, lessened financial security and threat to physical health each play an important role in generating and maintaining emotional trauma among the victims of disaster, and underdeveloped regions are particularly underequipped to cope (Norris, et al., 2002). As there was considerable variation in circumstance, there was also considerable variation in individual and social responses to the 2016 Kaikōura Earthquake (Gluckman, 2016). Sir Gluckman (2016) outlines a four-phase general framework to describe the changing psychosocial needs of a community over time following a disaster:

1) An altruistic phase immediately following the event, where people typically do not "count the costs" and will elect to see to the needs of others despite the impact to themselves.
2) An optimistic phase as help begins to arrive, and a general feeling of improvement is fostered.
3) A phase of disillusionment, where the realities of logistics interfere with emergency relief and recovery. The length of this phase is variable depending on feelings of empowerment, community resilience and access to aid.
4) A new equilibrium, where people adapt to the long-term reality of the disaster aftermath. This phase has no clear end and may last for years, if not indefinitely. It is typically characterised by a return to a pattern of "everyday life". It is important to acknowledge that uncertainty around the potential for future events will negatively affect recovery, and that relocation does not suddenly solve misgivings for those impacted by disaster.

It is the responsibility of local District Health Boards (DHB) to manage mental health, however this is not a simple task in the best of circumstances, let alone in remote rural communities (Gluckman, 2016). Several helplines that cater to rural mental wellbeing have been set up in the wake of the 2016 Kaikōura earthquake, as well as local support groups (Cook, 2016). Research suggests that most people recover from disaster-induced trauma in the long term, however at least 5 % will need ongoing professional assistance (Gluckman, 2016). The assignment of community navigators allows for both feedback to the DHB regarding needs as well as improving resident access to critical services (MCDEM, n.d.)(Section 3.5.4).

As part of an assessment of research priorities for this event, it was found through workshops that some people affected by the 2016 Kaikōura earthquake object to it being named as such (Hatton, et al., 2017). Hatton, et al. (2017) explain that this is due to perceived social and economic impacts to naming a disaster after a place. Participants in workshops echoed this point, citing disenfranchisement that Kaikōura township “seemed to be getting all the attention”, when infrastructure damage was widespread across North Canterbury and Marlborough (Canterbury Lifeline Utilites Group, 2018). Despite this, the label given to this event has already been firmly accepted in international literature, and for this reason the name “2016 Kaikōura earthquake” will continue to be used throughout this thesis. It should be noted that all sensitivity was exercised in the interviews for this thesis, and alternative naming conventions were used in person and in correspondence when appropriate.

1.4.3 Known Adaptations

As it took some time to restore services disrupted by the earthquake, community members needed to adapt their lifestyles, businesses and remaining infrastructure to overcome new hurdles in everyday life. Much of this came in the form of sharing labour and resources.

The isolation of Waiau by slips and road damage spurred farmers to assist one another and provide reassurance, as well as switching to gas barbecues in the absence of power (Stuff, 2016). It took some time before authorities restored water in urban areas of Waiau, however personal drinking water was not an issue for many farmers as rainwater storage tanks are the norm (Stuff, 2016). Although watering stock became an issue after a few days (ECan, 2016), personal water storage improved resilience for the farmers and their families (Stuff, 2016). ECan (2016) was one source informing farmers that they had the option to use fenced-off waterways for watering stock very soon after the earthquake. Following the Christchurch earthquakes, dairy farmers in Waiau also shared milking facilities to make up for damaged infrastructure (Stuff, 2016). This was not as widespread following the Kaikōura Earthquake, where guidelines for milk dumping needed to be circulated (ECan, 2016). These points encouraged us to research Waiau further.

1.5 Analogous Event Adaptations

Social, economic and physical changes to daily life underpin community adaptations to lifeline service disruption. Large earthquakes, such as the 2011 Christchurch earthquake, as well as other recent natural hazard events in New Zealand, including the 2006 Canterbury Snow Storm and 2008 Hurunui Floods, make good analogues for the Kaikōura earthquake with respect to community responses immediately following the event. Each of these events severely interrupted lifeline services and the chain of emergency administration.

1.5.1 2006 Canterbury Snowstorm

The 2006 Canterbury Snowstorm was an event that brought extreme levels of snow across the Canterbury region. As with the previously mentioned earthquakes, critical infrastructure supporting the electrical grid was severely damaged, leading to long term blackouts which consequently disrupted telecommunications in many places (Hendrikx, 2006; Wilson, et al., 2009). While direct livestock losses from the snowfall were minimal, the closure of roads and the failure of the electrical grid resulted in product and time wastage that did cause financial losses (Wilson, et al., 2009). Many local businesses donated their time and lent equipment to help restore lifeline services in the region, and where telecommunications were available some businesses went as far as checking if regular clients needed assistance (Wilson, et al., 2009).

1.5.2 2008 Hurunui Flooding

In 2008 the Hurunui District, also located in Canterbury, was inundated by heavy flooding during a storm event (Wild, 2014). Rivers overtopped their banks and covered roads and farmland in water (Wild, 2014). NZD$850,000 was invested in flood protection measures as a form of long term adaptation, mitigating the risk of future events primarily by repairing the Dock Creek flood control gate and developing river diversion works (Hurunui District Council, 2010). As data on historic flood events in the Hurunui District is limited, comprehensive computer modelling of flood risk and impact has been a priority for regional government (Griffiths & Holmes, 2014; Wild, 2014).

1.5.3 2011 Christchurch Earthquake

While not strictly small towns, some outer suburbs of Christchurch encountered similar issues to remote towns when lifeline services were disrupted by the Mw 6.2 2011 Christchurch earthquake. Limited resources to restore infrastructure encouraged the formation of community volunteer groups, as well as regular meetings to facilitate events such as neighbourhood barbeques (GNS Science, 2013). Pooling resources through such activities reduced the community- and family-level strain on material aid and aid workers, however the potency of this effect sharply declined with limited participation as the time following aftershocks grew (GNS Science, 2013). The capacity of families to adapt appears to be tied to how well-prepared for an earthquake they are beforehand (GNS Science, 2013). Out of the respondents to a 2013 GNS Science survey in Christchurch only 28 % were prepared to CDEM standards of basic preparation, comprising of emergency plans and supplies, resulting in a slow initial community response to the disaster and a heavy reliance on outside resource distribution (GNS Science, 2013).

1.6 Thesis Structure

This thesis is divided into five chapters as seen in Figure 1.6. Chapter 1 (this chapter) is an introduction, providing context and background for the other chapters. Chapter 2 contains the methodology of my investigation, including town selection and an interview framework. The two main content chapters that follow these conceptually form a letter 'T' shape – Chapter 3 is a broad view chapter looking across all four towns in my investigation and the 'bigger picture' of emergency management whereas Chapter 4 makes a more detailed assessment focusing on just one of the case study towns (Waiau). The majority of discussion takes place in Chapters 3 and 4, drawing heavily on original research from the interviews conducted as part of my investigation. Chapter 5 is a concluding chapter, summarising the findings of this thesis with a focus on key impacts and adaptations. It also identifies oppurtunities for future research.

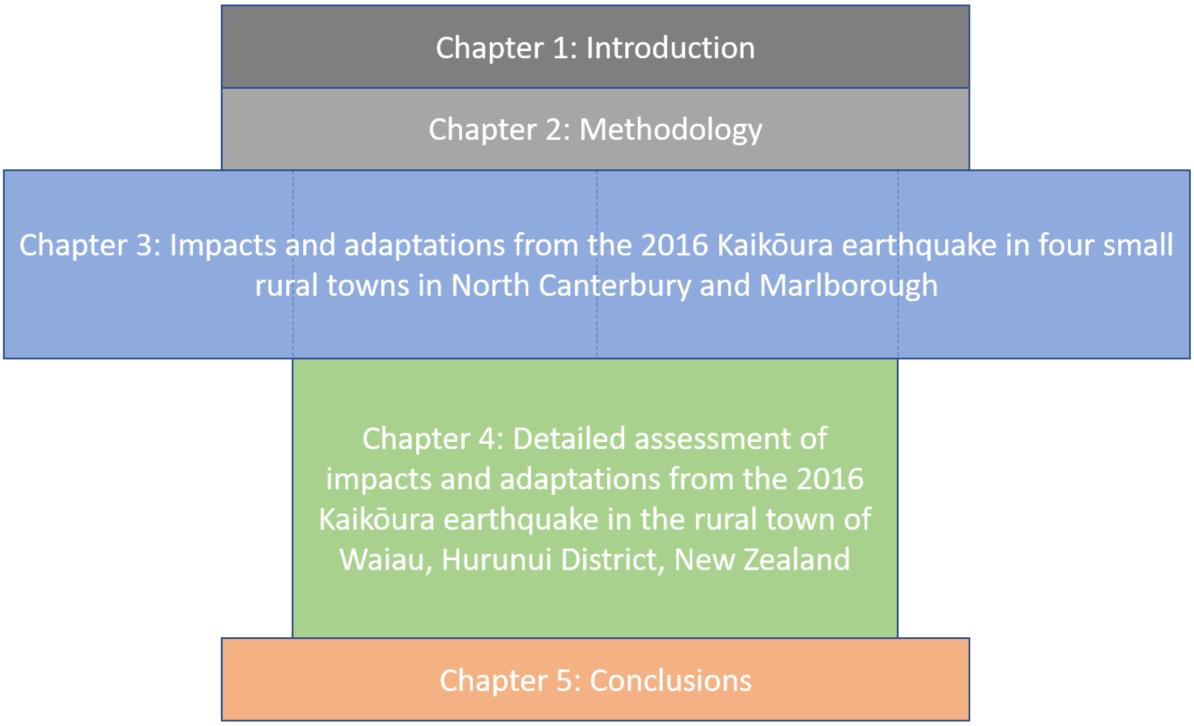


Figure 1.6: Diagram outlining the structure of this thesis

Chapter 2: Methodology

2.1 Research Focus and Chapter Overview

This chapter describes the methodology used to accomplish our three focus objectives. The first objective is to document the critical infrastructure impacts on small towns in North Canterbury and Marlborough. While impacts from the Kaikōura earthquake on large, urban population centres have been generally well documented, this thesis aims to fill gaps in academic knowledge regarding small rural towns. Building on this, any anticipated or actual adaptations to disruptions in lifeline service are examined. Such adaptations are recognised as a path to building resilience. Finally, an assessment is made on the success of these adaptations, and implications of future changes to infrastructure and environment are considered.

The chapter begins with an explanation of the town selection process, involving background research into various parameters of rural townships before being run through a selection matrix. Hazard and infrastructure maps are produced at regional and district levels for contextualising the environment and circumstances of the four selected towns. These are followed by an overview of the interview system used in this investigation.

2.2 Town Selection

2.2.1 Initial town selection

In the given time frame and scope of this thesis, it was feasible to investigate four towns. The following criteria were chosen to produce an initial pool of towns from news media, from which in turn specific towns for further consideration could be selected:

- The settlement is within the study area of North Canterbury, Kaikōura and Marlborough
- The settlement was reported to have been affected by the 2016 Kaikōura earthquake

2.2.2 Matrix for Case Study Town Selection

After identifying prospective towns it was necessary to choose the most appropriate for study (Figure 2.1). The matrix we use employs a traffic light system as an initial assessment of how suitable communities are for more detailed investigation in the project. This system has been adapted from the matrix used by the Resilience to Nature's Challenges (RNC) Rural team to select case studies in their 'Resilient Rural Backbone' project. The following key criteria (Table 2.1) were established after an initial examination of literature, including stage 1 of the New Zealand Lifelines Infrastructure Vulnerability Assessment, which directs the reader towards lifeline aspects considered significant in researching CDEM (New Zealand Lifelines Council, 2017).

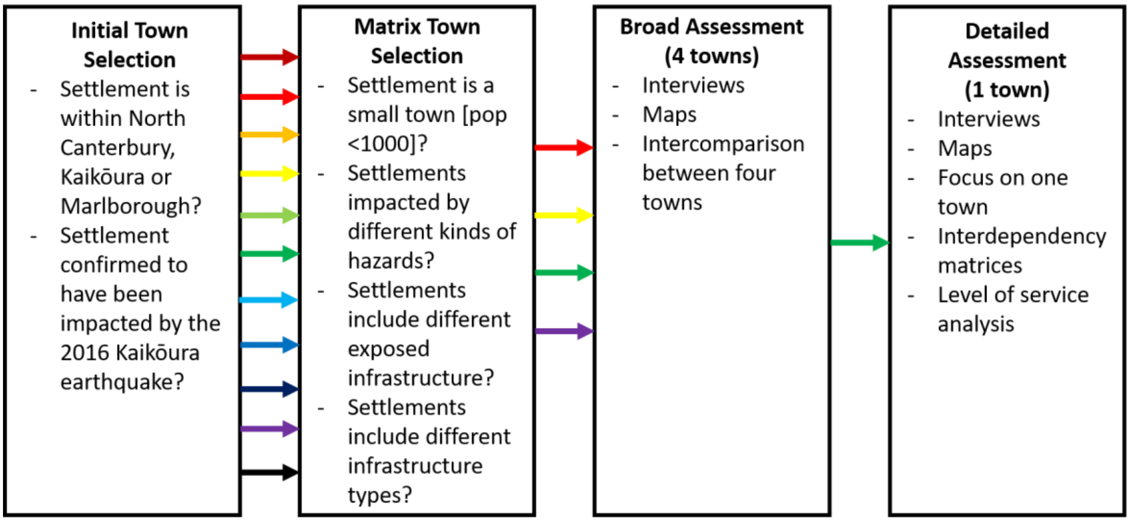


Figure 2.1: Town selection steps.

The hazard instances and impacts to infrastructure used in the matrix were primarily sourced from news media published online, through such reputable organisations as DairyNZ, Radio New Zealand, and The New Zealand Herald. While not a factually exhaustive source, the intent of this news media-based data collection was to develop and refine an initial selection pool – highlighting areas to focus our research in greater depth. This information was also used in identifying locally significant industries impacted by hazards. The types of co-seismic hazard indicated in this analysis are explored in greater detail in Chapter 1 of this thesis.

Locally significant industries were confirmed in the selected towns by supporting council website descriptions and with classifications from the land cover database developed by Landcare Research. A more direct approach may be to review economic statistics such as company asset reports. However, that data is not readily available in all cases and would not include a geospatial component, thus limiting our analysis.

Table 2.1: Matrix criteria explanation.

Criteria	Explanation	Assessment for Green
The settlement is within the study area of North Canterbury, Kaikōura and Marlborough	Our focus is on the communities directly affected by the 2016 Kaikōura earthquake within the North Canterbury and Marlborough regions	The community is within the North Canterbury and Marlborough regions (all communities listed)
The settlement is a small town	Our focus is investigating small rural communities	"Usual" population size <1000 (this is the permanent residential population)
The community has been reported to have been affected by the 2016 Kaikōura earthquake	It is not feasible to investigate every community for hazard impacts on infrastructure, so we have drawn on literature, reports and news media to identify initial candidates	The community has been reported to be affected in the mentioned documentation types (all communities listed)
There is a variety of key earthquake hazards represented in/among the communities	It would be valuable to compare perceived and actual risk between multiple earthquake hazards	Multiple key earthquake hazards are represented

There is a variety of impacted infrastructure types represented in/among the communities	It would be valuable to compare existing resilience to infrastructure damage and service disruption among many different infrastructure types. This should also diversify the adaptations available for study	Multiple infrastructure types are represented
There is a variety of locally significant industries represented in/among the communities	It would be valuable to compare the fragility and priorities of various industry sectors. This should also diversify the adaptations available for study	Multiple industry sectors are represented

2.2.3 Case Study Town Selection Criteria

Each community was assessed using the selection criteria outlined in Table 2.1, and the results are presented in Table 2.2. Red boxes in Table 2.2 indicate that criteria have not been met, eliminating the community from detailed study in this thesis, while amber boxes suggest that criteria have been at least partially filled. Fully satisfying a given criterion results in a green box. The colours have been weighted numerically to assist in selection, where red is worth **-12**, amber **1** and green **2**. Red represents a negative value specifically to disqualify towns which exceed a maximum parameter. Amber is a partial or poor fulfilment of conditions, whereas green is an optimum fulfilment of conditions.

Towns which have exceeded the 'usual' population limit, a classification used by the New Zealand Census to describe permanent residential population, received a red rating for criterion 2 and have been eliminated from further study. Census population data is preferred over unofficial or absent data sources. Data on transient populations is notoriously difficult to quantify and is not available for most of the prospective communities. For this reason, only 'usual' populations are considered for the selection matrix. The towns in Table 2.3 best fit the selection criteria proposed in Table 2.1.

Table 2.2: Selection matrix. Green is worth 2 points, amber is worth 1 point. Red is worth -12 points to disqualify that community from selection. Final scores accompanied by an asterix denote communities with poor or no population data. Communities

Criteria	Awatere Valley	Culverden	Goose Bay	Grovetown	Hapuku	Kaikōura (rural)	Kaikōura (town)	Kēkerengū	Lyford Village	Rakautara	Seddon	Waiau	Ward
Within the study area													
Affected by earthquake													
'Small' community	NO DATA		POOR DATA	POP TOO HIGH	POOR DATA	POP TOO HIGH	POP TOO HIGH	NO DATA	NO DATA	POOR DATA			
Variety of hazards													
Variety of infrastructure													
Variety of industry types													
Scoring	8*	10	9*	-5	10*	-2	-2	10*	8*	8*	11	11	12

2.2.4 Exposure

A preliminary infrastructure exposure inventory, developed from both GIS tools and literature, was considered for Table 2.3 to guide our investigation and identify key elements. Where critical infrastructure is absent from the inventory, we can assume that either nearby communities host and share the services with the community in question – a form of interdependency – or that there is simply no data readily available. A comprehensive exposure inventory (Chapter 3.2) was established with information gathered from interviews and workshops.

Table 2.3: Table of selected towns with justification.

Criteria	Culverden	Seddon	Waiau	Ward
Matrix score	10	11	11	12
'Small' community	'Usual' population of 426	'Usual' population of 507	'Usual' population of 261	'Usual' population of 930
Hazards	Landslides Shaking Liquefaction	Landslides Shaking Surface rupture	Landslides Shaking Surface rupture Liquefaction	Landslides Shaking Surface rupture Uplift
Impacted infrastructure	Roads cut off Power outages	Roads cut off Water supply compromised	Roads cut off Power cut off Water pumps not powered	Roads cut off Power outages Water supply cut off Septic tank connections damaged
Variety of industry types	Farming hub Farming (pastoral)	Farming (pastoral and short-rotation cropland)	Farming (pastoral and short-rotation cropland)	Farmland (pastoral, manuka and/or Kanuka) Seafood processing
Exposed infrastructure inventory	Roads Distribution power networks Wastewater Sewage	Roads Distribution power networks Wastewater Sewage	Roads Distribution power networks Wastewater Sewage	Roads Distribution power networks Wastewater Sewage

	Residential (rural to suburban) Industrial Schools Supermarkets Fuel stations Police stations Fire stations Ambulance stations Fonterra Facility	Residential (rural to suburban) Industrial Schools Railway line Supermarkets Fire stations	Residential (rural to suburban) Industrial Schools Health Centres Fuel stations Fire stations	Residential (rural to suburban) Industrial Schools Railway line Fuel stations Police stations Fire stations
Known adaptations or self-recovery	N/A	Volunteers repair road between Seddon and Kekerengu Residents advised to boil town water supply	Farmers sharing manpower, switched to gas barbecues for cooking Following Chch earthquakes farmers shared milking facilities to relieve cows	Makeshift welfare centre was set up in the local community hall
Evidence of interdependen ce	As a farming hub, nearby rural communities such as Waiau rely on Culverden as part of their chain of production	Considered a 'choke point' to Kēkerengū, transport needed to be restored before aid could be distributed in Kēkerengū	Power needed to be restored before pump systems could resume water distribution	All roads into Ward were cut off and broken bridges specifically represent choke points for other services such as fibre and power

2.3 Data sources

2.3.1 Hazard Maps

The hazard component of our equation for resilience varies widely across the study area for multiple hazard types. Shaking severity is approximated here by Modified Mercalli Intensity (MMI), taken from Bradley et al. (2017). It should be noted that the 2016 Kaikōura earthquake was unusual in that it propagated along a complex series of fault ruptures northwards from the epicentre, resulting in an elongated patch of high MMI (Figure 2.2).

These ruptured faults are depicted in red on Figures 2.2, 2.3 and 2.4. Seismogenic landslides have been investigated by several studies at varying degrees of reliability and completeness (Sotiris, et al., 2016; Rosser, et al., 2017; Massey, et al., 2018), however we have chosen to apply the dataset from Massey, et al. (2018) here as it appears to have the most complete and accurate data within close proximity to our towns. Geospatial datasets for surface rupture, lateral spreading and liquefaction have been difficult to source and for this reason, these hazards will be revisited in subchapters concerning specific hazard impacts.

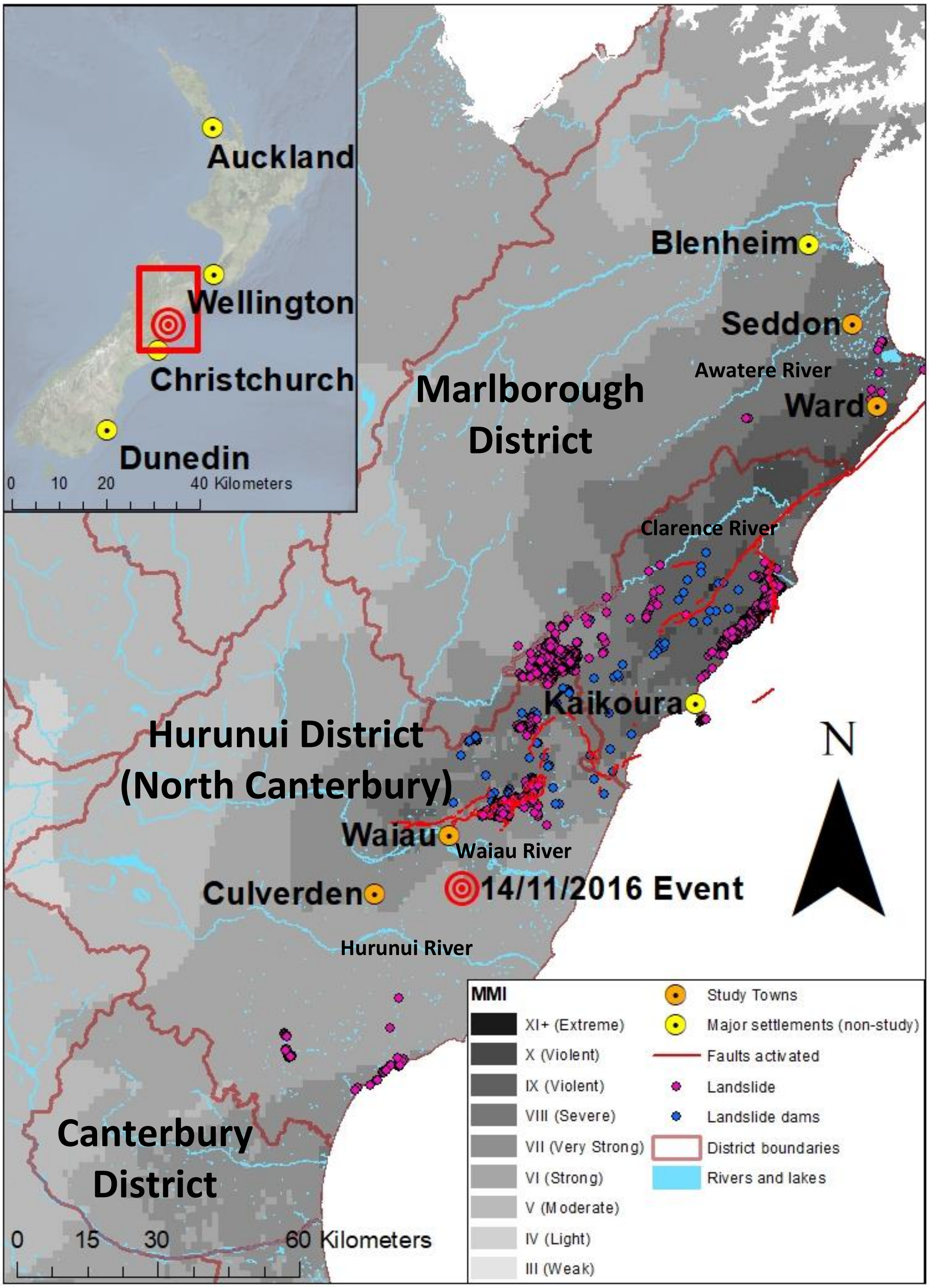


Figure 2.2: North Canterbury & Marlborough hazards.

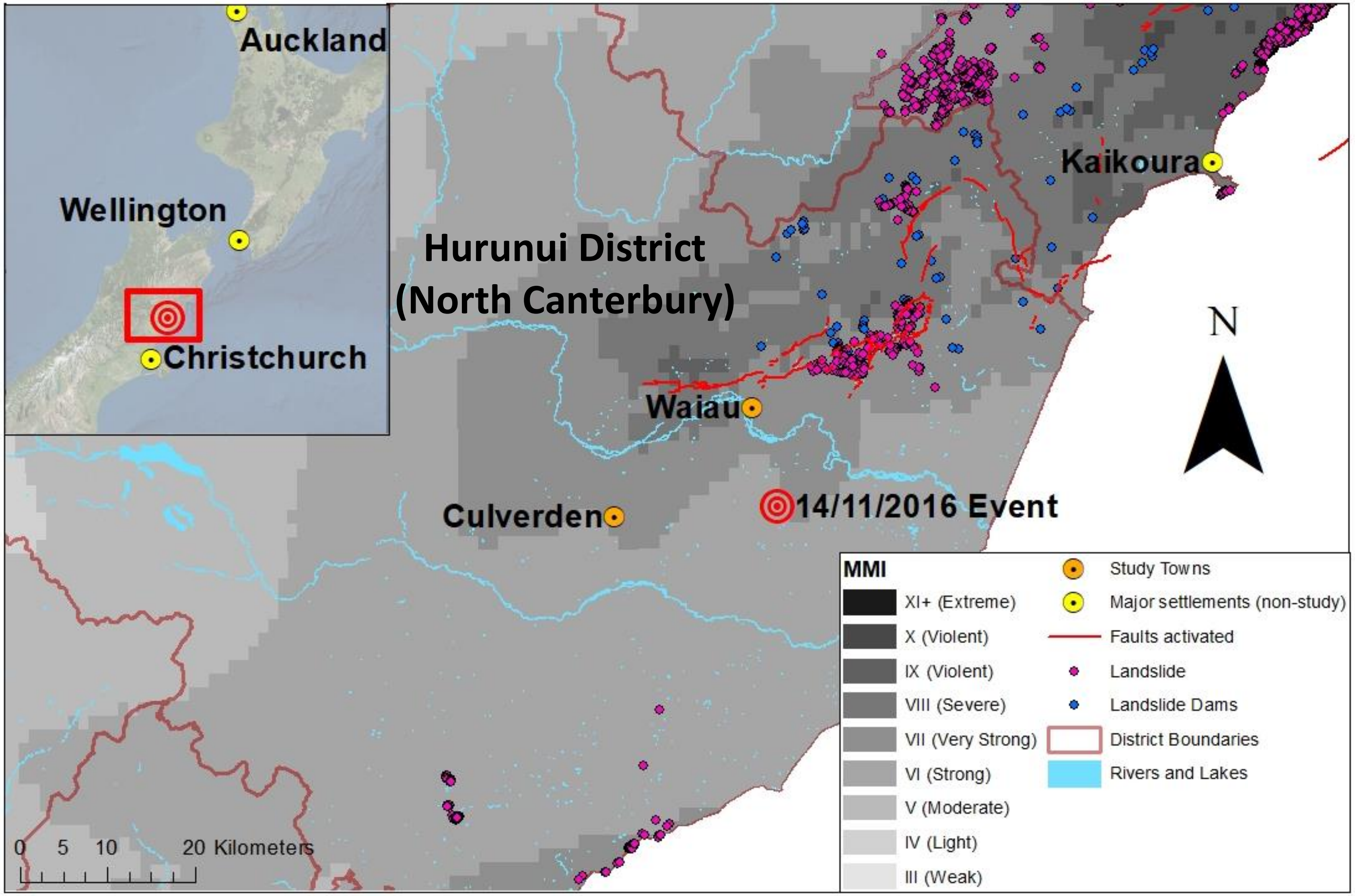


Figure 2.3: Hurunui Hazards

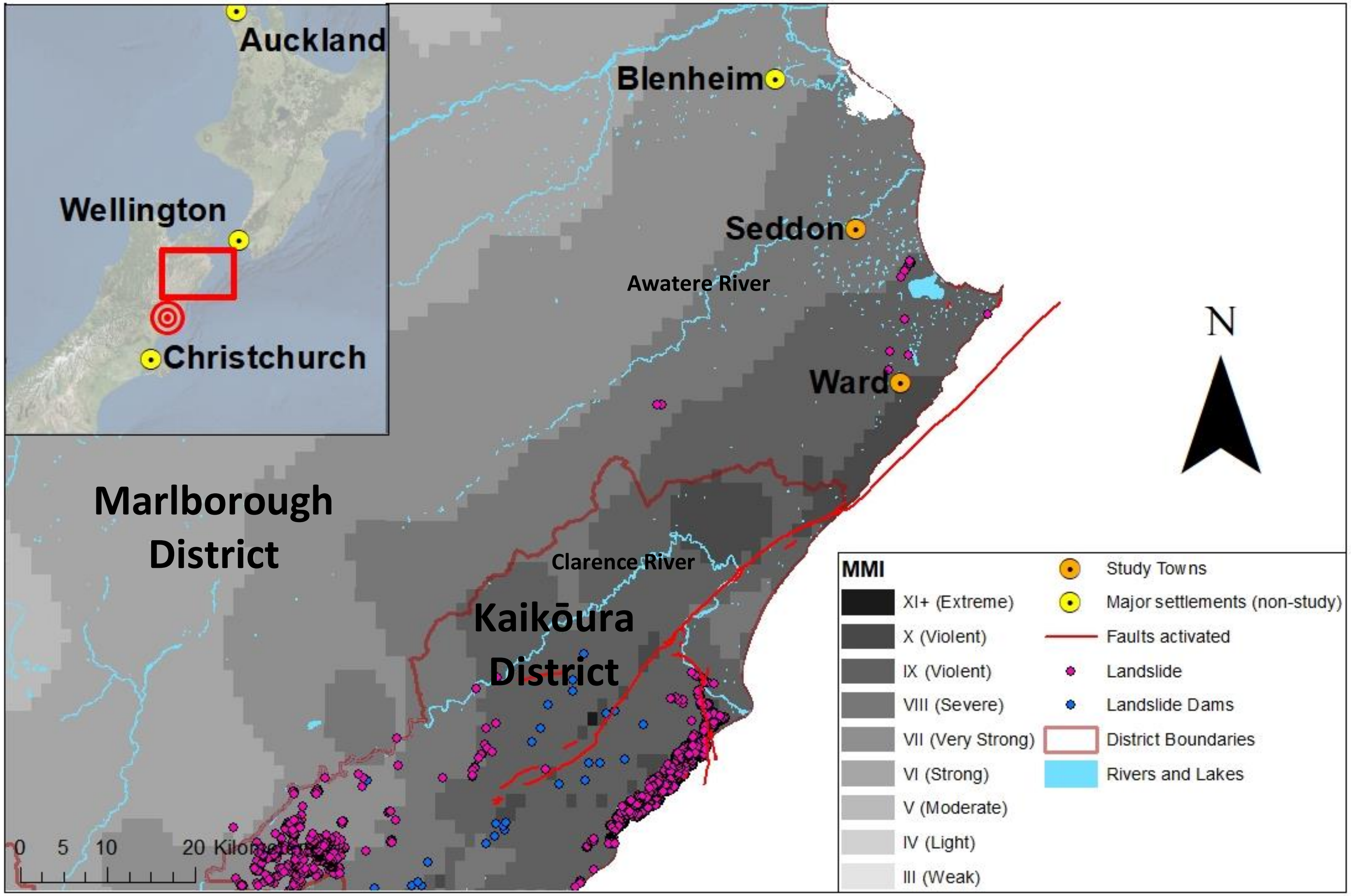


Figure 2.4: South Marlborough hazards

2.4 Infrastructure Inventory Maps

Together with the previous hazard maps, infrastructure inventories offer geospatial context to hazard exposure – the E component of our resilience equation. This consists of critical infrastructure networks, facilities, and components. In this section we present critical infrastructure inventories for the overall study area (Figure 2.5) and partial district (Figures 2.6 and 2.7) levels. Smaller scale inventories for specific towns can be found in Section 3.2.

The 2011 road network shapefile (TOPO 1:500) was taken from the Land Information New Zealand (LINZ) database. State highways have been boldened to signify their class (Figure 2.5). As this data did not differentiate bridges from grounded roading, a separate bridge shapefile (TOPO 1:150k) was also sourced from LINZ and overlain on the road network.

To represent the electrical network we have used the transmission infrastructure of Transpower, the state owned infrastructure manager for electricity transmission in New Zealand. The nodal "sites" are undifferentiated from each other in the source file, however additional research showed these to be mainly grid exit points (GXPs). Transmission lines take power from generator stations to GXPs, where it is then spread to consumers by a local distribution network at reduced voltages. The distribution network that services much of Kaikōura and the Hurunui district was obtained for our analysis, however we do not have permission to republish it here. At smaller scales we can cleanly display the location of critical facilities. These include hospitals, schools and stations for the emergency services. Critical facilities were located with assistance from the Critchlow Emergency Management Basemap, Google Maps and input from interviewees. These town-specific maps are found with detailed town descriptions in Section 3.2.

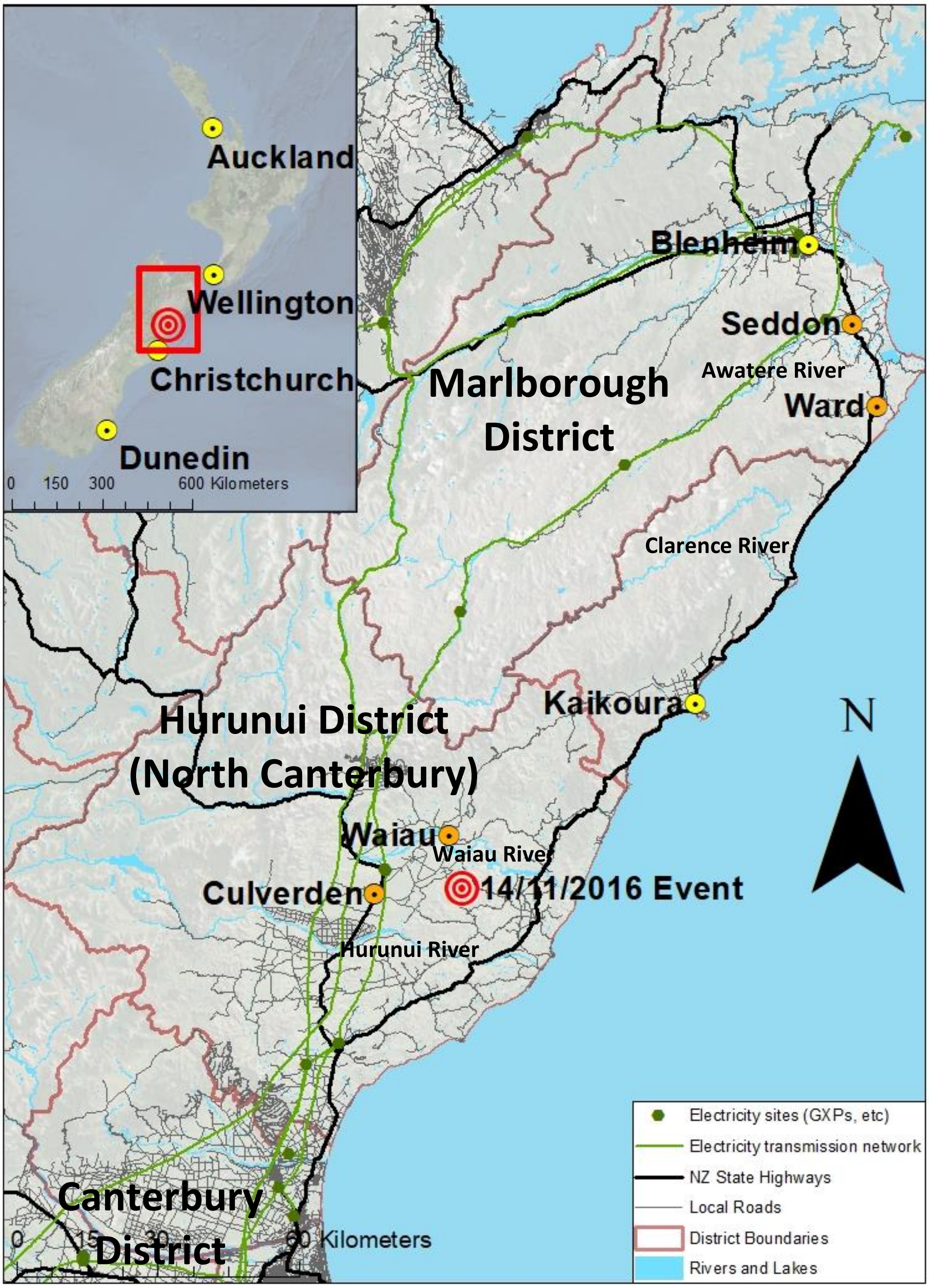


Figure 2.5: North Canterbury & Marlborough infrastructure.

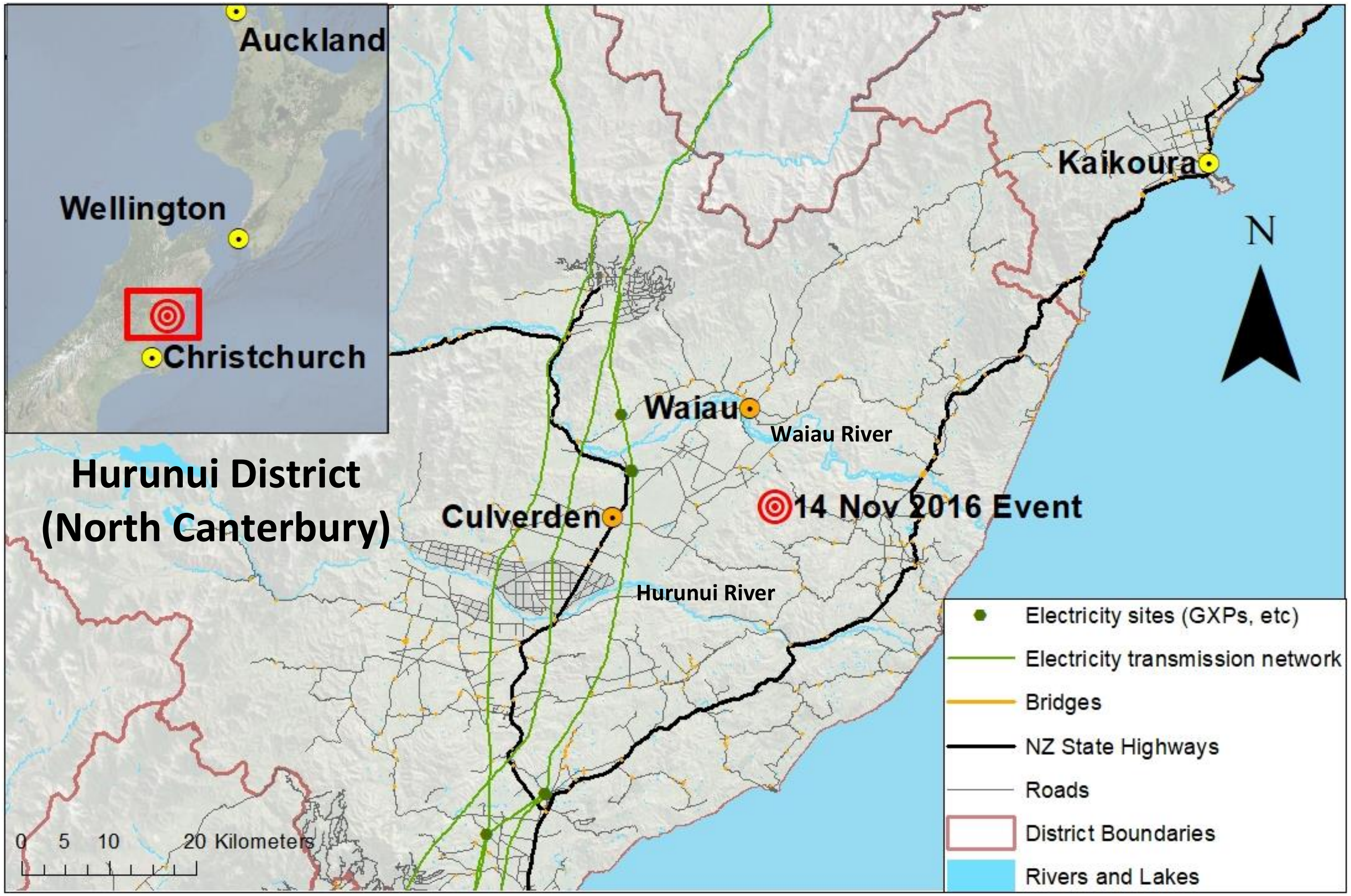


Figure 2.6: Hurunui infrastructure.

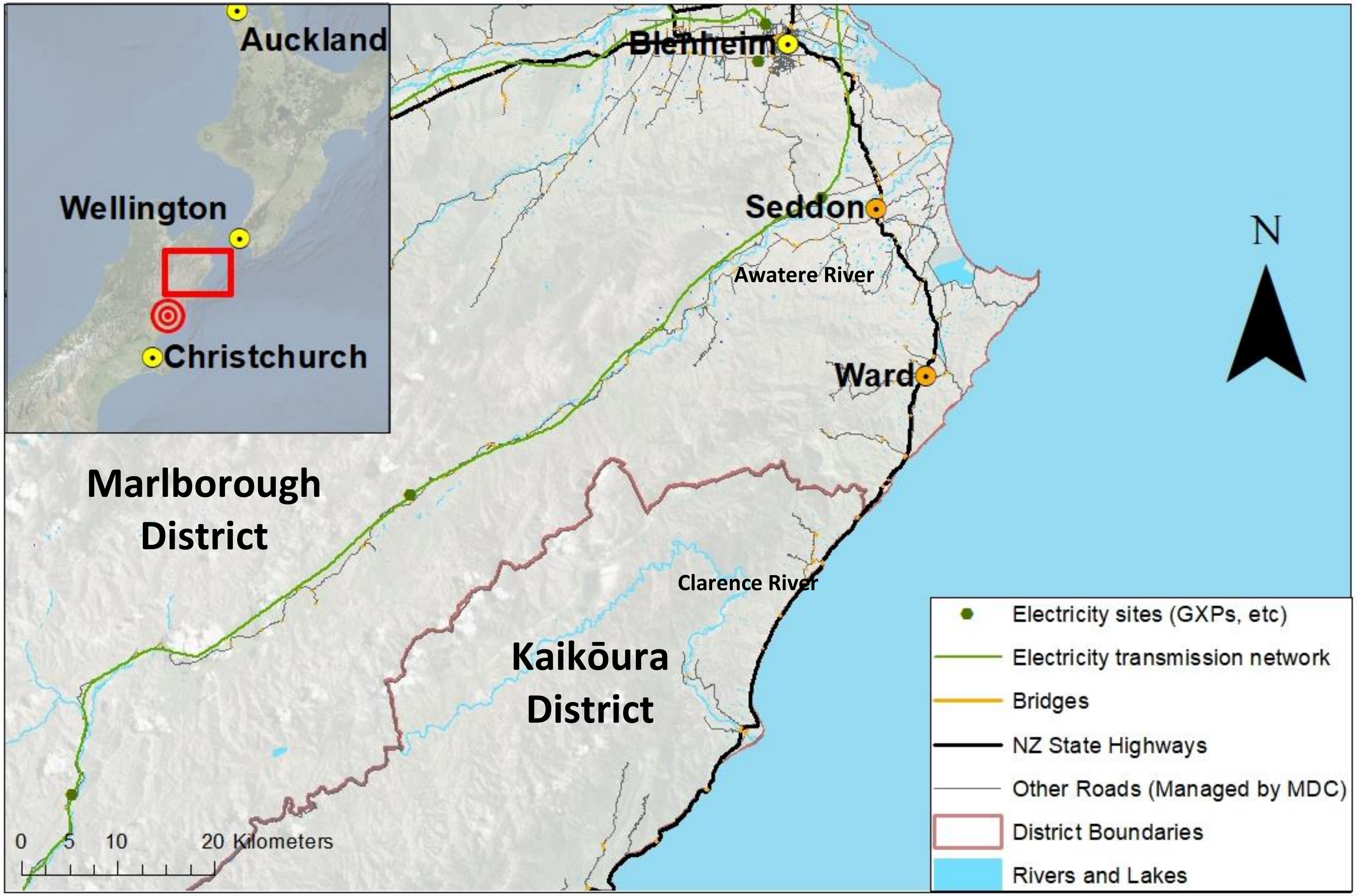


Figure 2.7: South east Marlborough infrastructure.

2.5 Interviews

Interview methodology for this project was approved by the New Zealand University of Canterbury Human Ethics Committee prior to engagement with participants. Interviews with infrastructure managers, emergency management officials and other experts were critical in gathering data for this project. Situational reports, debriefs, media releases and previous research studies all focus on accomplishing set objectives in contexts different to our own. This leaves several gaps in the literature review that must be filled, clarified or expanded. Additionally, literature with distinct objectives can often cloud original context or reduce resolution of data to a point where details important to our investigation are overlooked. First-hand collection of data from interviews is thus extremely valuable.

Before asking questions, we encouraged interviewees to recount their professional experience of the event. This allowed the interviewee the opportunity to tell their story and provide context for our session. We applied a semi structured style of interview with a few guiding questions to keep discussion relevant, customised to be appropriate for each interviewee. Some customisation was conducted before each interview and some occurred 'on the fly' after hearing the experience during the interview. A semi-structured approach was required to allow slight deviation from the interview structure to clarify certain points or follow a productive line of thought at times. This had the additional intent to make discussions feel more natural and comfortable for all involved. The stock guiding questions were as follows:

- What were the impacts (failure and disruption) to critical infrastructure?
- Where, when and why were critical infrastructure services affected?
- Which critical infrastructure types are most vulnerable?
- Which critical infrastructure types have the greatest perceived and actual effect on communities?
- In which geographic and socioeconomic settings are communities more vulnerable to lifeline service disruption?
- What specific disruptions are driving adaptation?
- Where are disruptions occurring?
- When are disruptions occurring?

- Where several lifeline services are disrupted, is there a hierarchy of service priorities? Does this match community needs?
- What anticipated and actual adaptations do small communities make in response to critical infrastructure service disruption?
- How successful are these adaptations?
- Who directs or oversees adaptative behaviour?
- What adaptation strategies exist to deal with critical infrastructure service disruption?
- Were, where and when these strategies implemented, and to what success?
- What went well, and what could be improved?
- Any further comments on recovery in hindsight?
- What current plans are there to improve resilience?

We officially engaged with 15 participants across 12 sessions in organisation offices or neutral spaces such as cafes. Participants were mostly district-level infrastructure managers, or involved in some other role that brought them into the response and recovery of one or more of the selected towns. In order to preserve context and factual accuracy, audio recordings of each session were made if the interviewee consented. These recordings will not be made available for review to protect personally identifying information. Assuring anonymity was important in this project so that information and opinions could be freely shared, especially content which had otherwise not been published in official reports. In spite of this, organisation dominance and regional monopolies in industry make true anonymity difficult. We have done our best to mitigate this by omitting identifying information where feasible, as declared in the approved University of Canterbury ethics application.

Large printed copies of infrastructure inventory maps at different scales were brought to sessions as communication and memory aids. By recording the position of certain infrastructure, hazards or events on the maps we gained unique insight and could incorporate these additions in successive iterations of electronic maps. Revision and editing in the presence of experts ensures accuracy and helps to build a stronger picture of events for both interviewer and participant. Additional materials such as datasets and images were obtained from some interviewees.

2.6 Interdependency Matrix

The consequences of service disruption can be complex and far-reaching, impacting the ability of other services and even whole communities to function. It is therefore valuable to include interdependencies in our analysis. Interdependency matrices were developed based on examples given in the New Zealand Lifelines Council's Lifelines Infrastructure Vulnerability Assessment. These matrices represent lifeline interdependence criticality during business-as-usual and post-event, showing which lifelines services are most relied on by other lifelines in business-as-usual and post-event scenarios. The values given are semi-quanititive and based on input from a literature review and the interviews.

Chapter 3: Impacts and adaptations following the 2016 Kaikōura earthquake in four small rural towns in North Canterbury and Marlborough

3.1 Chapter overview

Chapter three is the first of two chapters to present findings from original research, namely outputs from interview sessions with infrastructure managers and experienced members of other organisations involved in response, recovery and resilience. This chapter analyses impacts and adaptations across the four case study towns selected in the previous chapter (Ward, Seddon, Waiau and Culverden) and any interactions between these towns following the Kaikōura earthquake. We then evaluate the success of these adaptations. The chapter begins with a brief background of each town and notes on the accompanying infrastructure inventories, before detailing characteristics on the built environment. Much of the focus is on critical infrastructure, important facilities and the services they support. This is followed by a section on socioeconomic response to the earthquake, involving such issues as transient populations, the 'township vs producing land' dynamic and socioeconomic barriers to developing resilience. The final section reviews the governance of risk and resilience, specifically engagement with communities, legislation and the expansion of Marlborough District Council's (MDC) remit to include the Clarence and Kekerengu river valley communities following the earthquake. The bulk of the information presented in this chapter is drawn from the findings of the interviews described in Chapter 2.

3.2 Background of Towns

The four towns in our investigation are split between two districts to the north and south of Kaikōura. Essential information regarding these towns can be found in Table 3.1. Culverden and Waiau lie in Hurunui district. South east Marlborough harbours the towns of Seddon and Ward. Coincidently, the towns in each pair are very close to one another – offering opportunities to observe co-dependence on infrastructure and socioeconomic links. It should be noted population data for these towns is taken from the 2013 New Zealand Census, however the meshblocks used in classifying locales for the census may not match our study areas. The boundaries of rural towns are not often clear without some sort of geographical feature, such as bordering rivers or the ridges of a water catchment, which are incorporated for the study areas used in this thesis. Additionally, population activity such as employment may expand the relevant study area of a town and is also considered here.

Table 3.1: Case study towns. For maps of these towns, see Figures 3.1, 3.2, 3.3 and 3.4.

Name	Population	Description
Culverden	426 (Stats NZ, n.d. b)	A town in the Hurunui District of the North Canterbury region (Figure 3.1). Considered the 'hub' of farming in the district, it is the commercial centre for many agricultural activities for Waiau and other localities in the Amuri Basin (Hurunui District Council, n.d. a).
Waiau	261 (Stats NZ, n.d. c)	Waiau is located just north-east of Culverden within the Hurunui District in North Canterbury (Figure 3.2). The township is involved in services which support large-scale farming.
Seddon	504 (Stats NZ, n.d. d)	Seddon is situated in the Marlborough District and region (Figure 3.3). Major industries here include farming, lime quarrying and the Lake Grassmere salt ponds. Seddon is located close to the epicentres of the previous 2013 Seddon and 2013 Lake Grassmere earthquakes (Table 1.1).
Ward	930 (Stats NZ, n.d. e)	Ward is the second town we are investigating in the Marlborough District and region (Figure 3.4). Pastoral farming and fisheries are the industries of greatest importance to the township. One property on SH1 is multipurpose, serving as a pub, petrol station and general store.

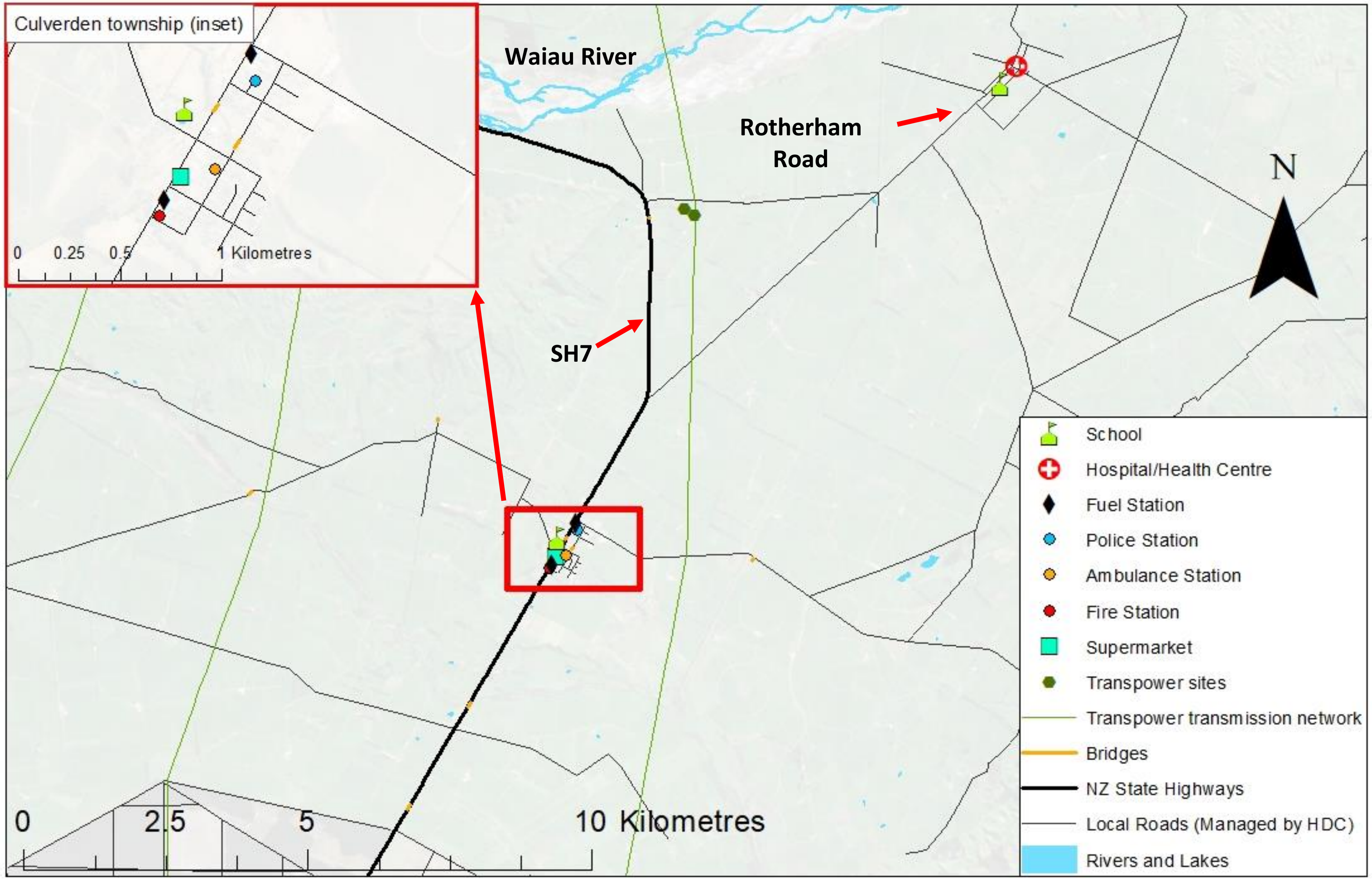


Figure 3.1: Culverden Town Exposed Infrastructure

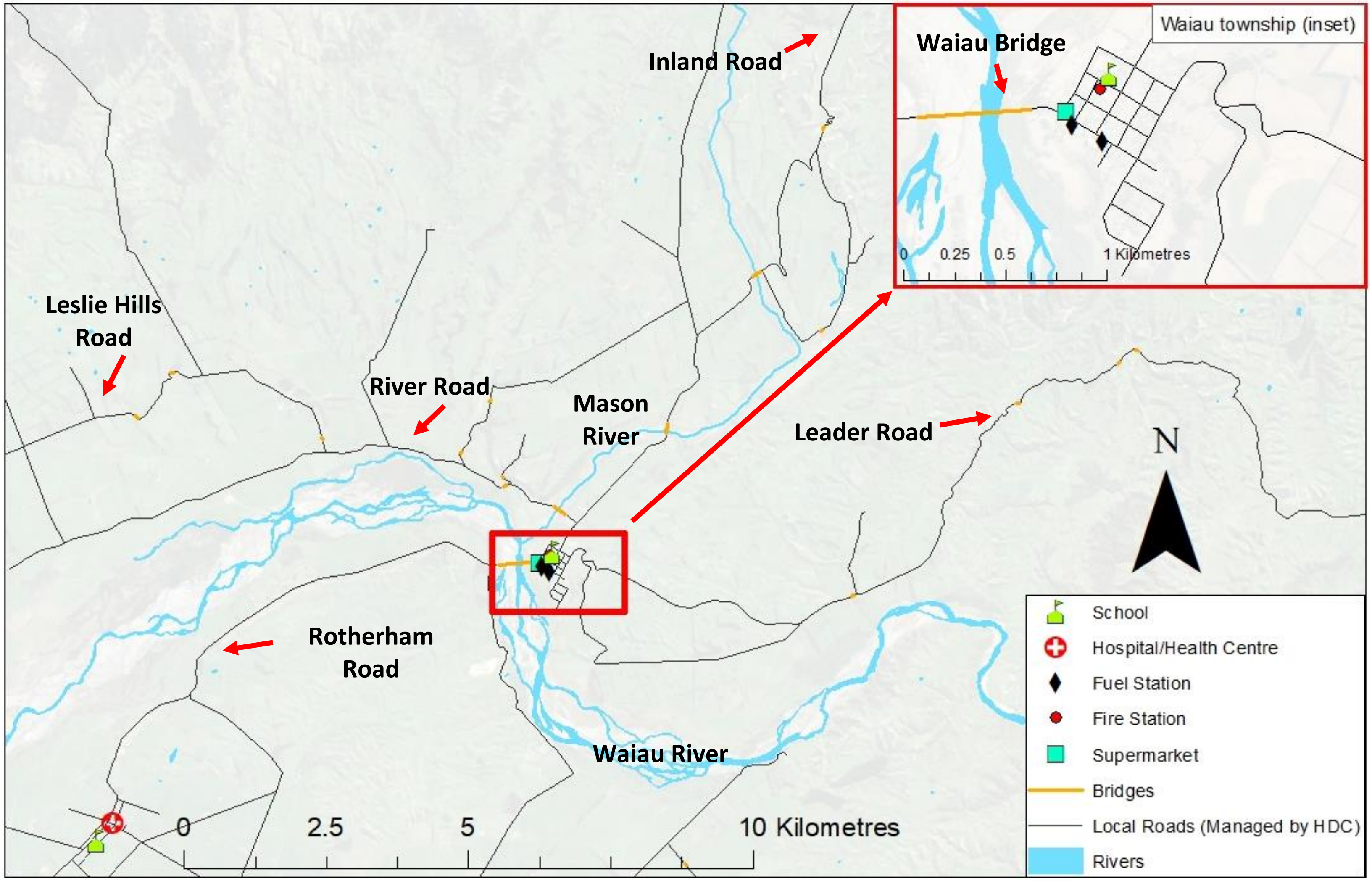


Figure 3.2: Waiau Town Exposed Infrastructure.

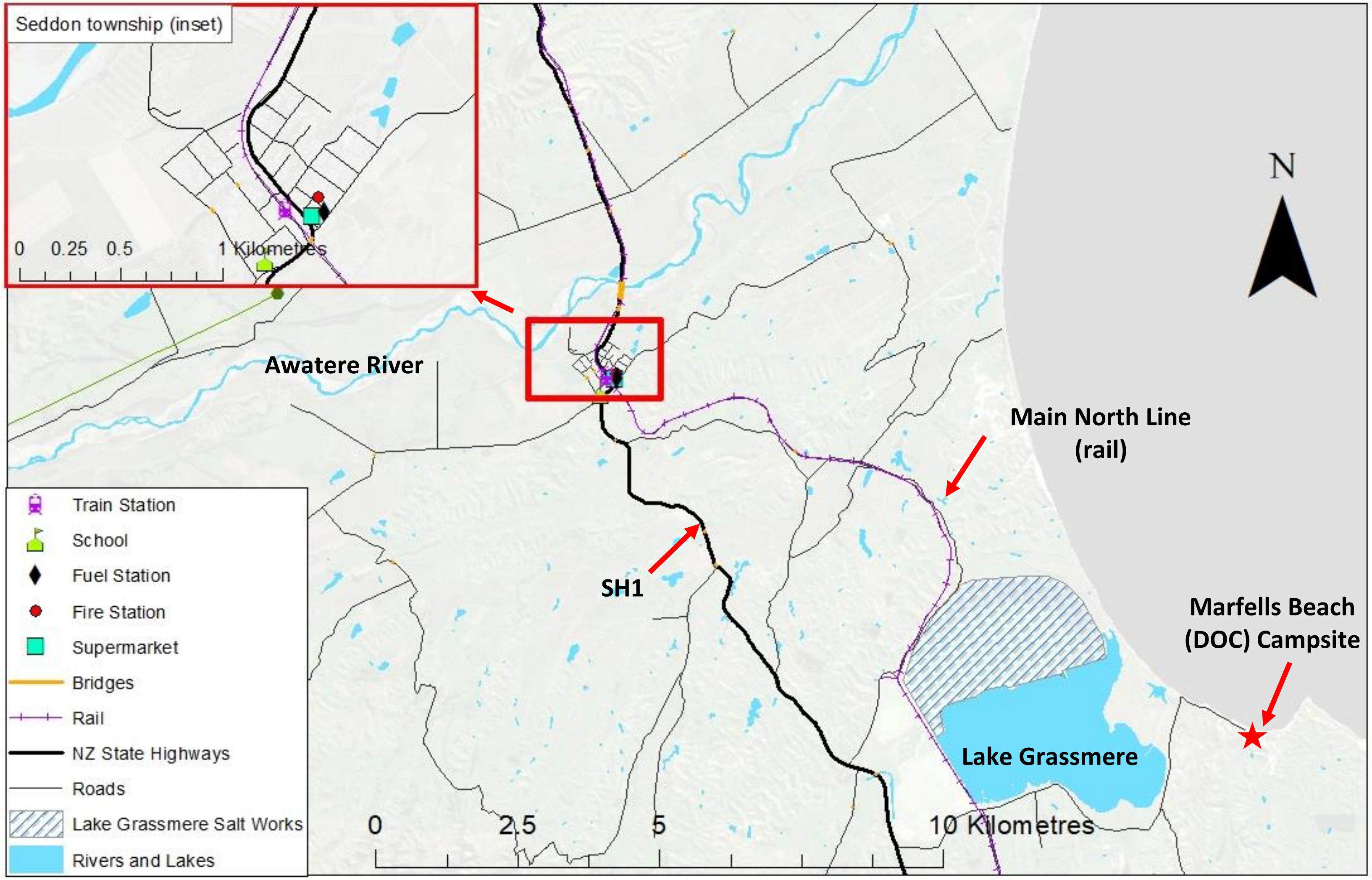


Figure 3.3: Seddon Town Exposed Infrastructure.

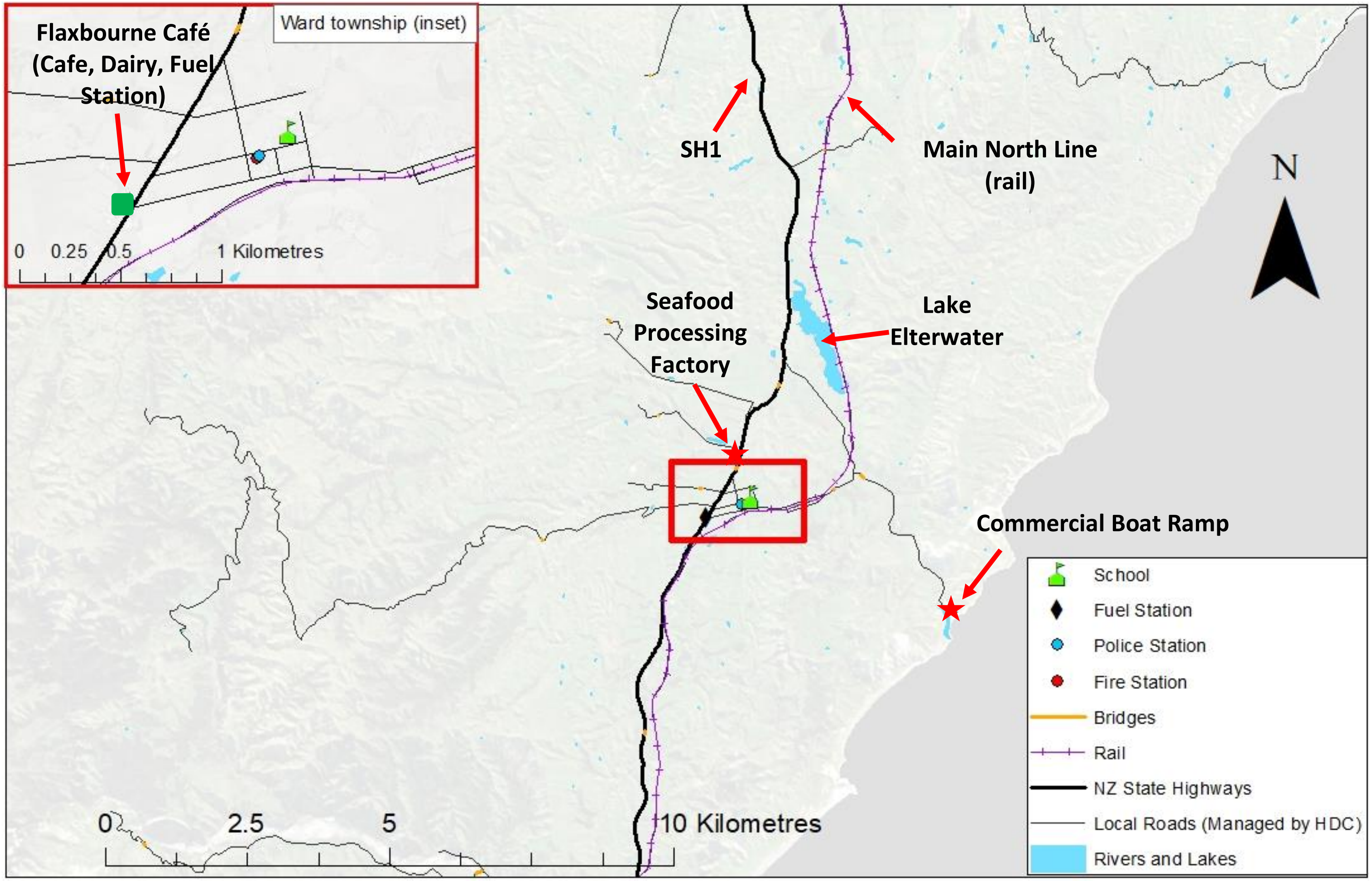


Figure 3.4: Ward Town Exposed Infrastructure.

3.3 Built Environment

The built environment encompasses all the physical infrastructure in the study area. For the purpose of this thesis this have been divided into two main categories, each with distinct geospatial characteristics: termed 'critical infrastructure networks' and 'critical facilities'. Critical infrastructure networks incorporate a wide network of interconnected structures and spans, including roads, water schemes, electrical grids and telecommunications. These connect the many remote communities of rural Marlborough and North Canterbury, however remoteness, terrain and low population has ensured that few redundancies in linear networks are economically feasible. Critical facilities are distinguished here as individual pieces of infrastructure which are not inherently part of a larger network. Examples of this may include residences, schools, supermarkets and restaurants – all of which may rely on networked infrastructure such as the electrical grid to function, but are managed independently and provide a service unique from the networked infrastructure they rely on. These should not be confused with nodes in infrastructure networks, such as GXPs, which still play a fundamental role in and rely on the rest of the electrical grid. A number of infrastructure networks and critical facilities are summarised for each town in Table 3.2.

Table 3.2: Exposed Infrastructure Inventory for the case study towns

Culverden	Waiau	Seddon	Ward
- Roads - Transmission power networks - Grid exit points - Distribution power networks - Three waters - Residential (rural to suburban) - Rural industrial - Schools - Health centre - Supermarket - Fuel stations - Police stations - Fire stations - Ambulance stations - Fonterra Facility	- Roads - Distribution power networks - Three waters - Residential (rural to suburban) - Rural industrial - Schools - Fuel stations - Fire stations	- Roads - Transmission power networks - Grid exit points - Distribution power networks - Three waters - Residential (rural to suburban) - Rural industrial - Schools - Railway line - Fuel stations - Supermarket - Fire stations - Grassmere salt ponds	- Roads - Distribution power networks - Three waters - Residential (rural to suburban) - Rural industrial - Schools - Railway line - Fuel stations - Police stations - Fire stations - Commercial boat ramp - Seafood processing factory - Multipurpose café (also fuel station and dairy)

3.3.1 Transport Networks

3.3.1.1 Bridges and Roading

Road jurisdictions in New Zealand are split between district councils looking after local roads, and central government maintaining state highways through the NZ Transport Agency. The general workflow for restoring roading begins with highways, which form the backbone of overland transportation. Some highways were unable to be restored in a timely manner due to significant landslides, such as along some coastal tracts of SH1. The NZ Transport Agency together with KiwiRail and key transport contractors developed the North Canterbury Transport Infrastructure Recovery (NCTIR) alliance to spearhead the restoration of SH1 and the accompanying coastal railway. Access along State Highway 1 was blocked for more than a year following the earthquake, only reopening recently at a reduced capacity on the 15 December 2017 (NCTIR, 2017b).

Marlborough and North Canterbury roads were severely disrupted by surface rupture, lateral spreading and landslides. To a lesser extent liquefaction was also observed, however its impact on roads in Marlborough was negligible. Surface rupture damage to roads in Marlborough was concentrated towards the mid to south. Roads blocked by slips near Seddon were cleared by locals in early morning following the earthquake (15 November 2016), speeding up response time for vehicles coming along SH1 through Seddon and Ward (Newton, 2016). 904 road bridges across Hurunui, Marlborough and Kaikōura districts were affected, however only two exceeded minor to moderate damage (Palermo, et al., 2017). Palermo, et al. (2017) primarily attributed this damage to ground shaking intensity.

Fallen electrical conductors blocked many roads. These were mostly removed within a couple of days by utility recovery personnel as part of electrical infrastructure recovery, however they represent a negative interaction between one type of infrastructure failure and disruptions in an otherwise independent lifeline service. In Marlborough all roads were open in a driveable state within three days, excluding Awatere Valley Road which took nine weeks. This road, west of Seddon, was infamously blocked by the landslide in Figure 3.5, isolating the Awatere Valley community by road. Some road status information was initially not signposted well as there were not enough road traffic restriction signs available.

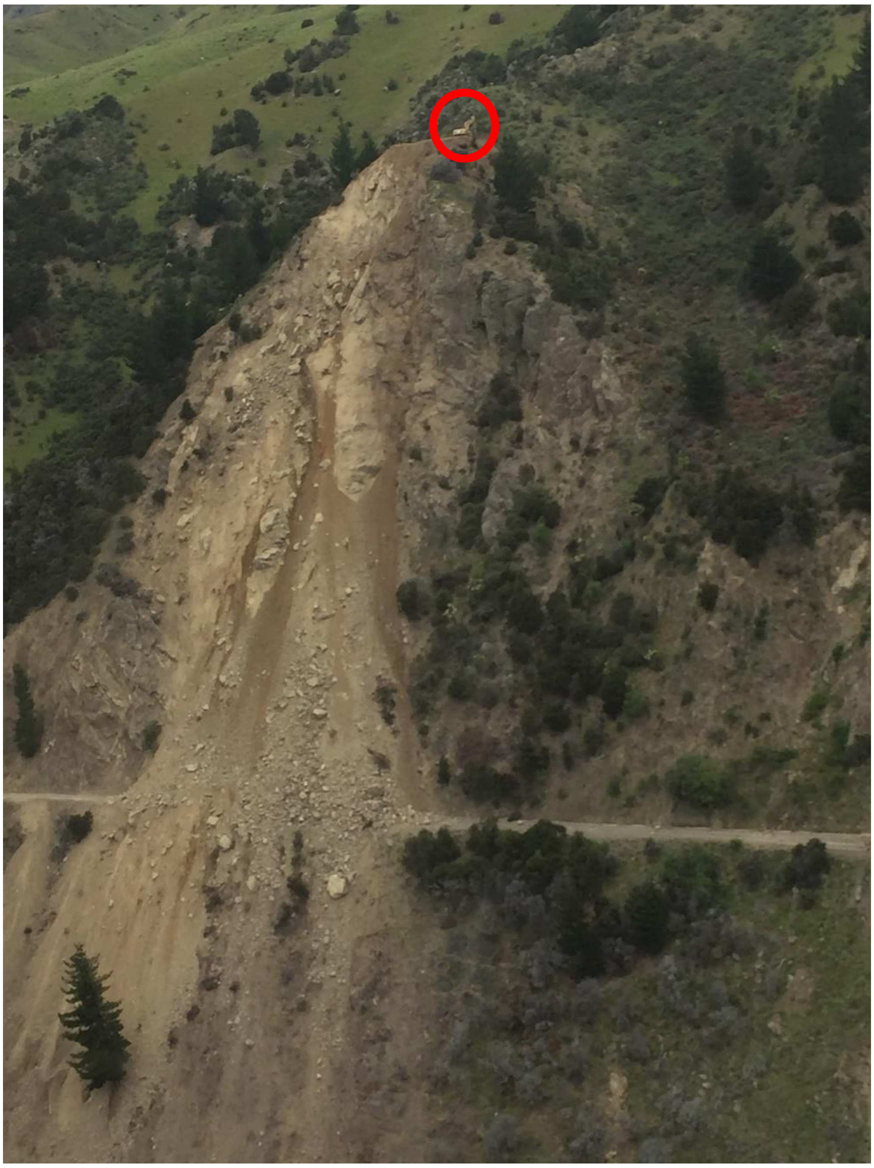


Figure 3.5: Awatere Valley Road blocked by landslide, excavator for scale (Steve Murrin, 2016).

The management and restoration of major roads is mostly left to local district councils, with the exception of certain routes such as the Inland Road which the NZ Transport Agency gained responsibility for due to its significance in accessing Kaikōura. Once major roads are restored, minor roads are prioritised based on usage. This standard system is modified based on the degree of road damage and the access needs of other critical infrastructure repair groups. In Marlborough there was good communication in this respect as relationships had already been made following the Seddon/Grassmere earthquakes.

An initial approach to slumping abutments and cracked roads was to reseal them, however continued slumping from aftershocks and ground settling made this inefficient compared to simply covering roads with gravel as a temporary solution. In one case, a set of abutments had been repaired as many as six times. The Seddon earthquake had similar impacts on bridge abutments, so this lesson carried over for many people in Marlborough. The gravel used in these roadworks was sourced locally from any of the numerous gravel bed rivers across the study area, notably the Waiau, Ure and Awatere rivers. Environment Canterbury (ECan) sought to work closely with farmers on extracting gravel for repairing private roads and farm tracks, providing 'gravel authorisation' in order to better manage resources in North Canterbury (Environment Canterbury, 2018). MDC issued similar gravel extraction consents for Marlborough. Workers extracting gravel frequently reported concerns around the likelihood of landslide dams collapsing upstream, however these were being carefully managed by ECan with assistance from GNS Science. A GIS-based system for tracking road status was adopted by MDC post recovery. This 'RAMM GIS' would have been useful in coordinating with other lifeline infrastructure managers and feeding up to date, accurate information to authorities and public alike.

3.3.1.2 Alternative Transport Modes

Aircraft were used frequently immediately following the earthquake, to transport personnel such as politicians, tourists, infrastructure management crews, and news media. They were also used extensively in surveying and monitoring damage from the earthquake, particularly landslide dams and remote swathes of critical infrastructure networks. Aviation fuel supplies in Marlborough became a concern very early on, as traditional overland transport routes along SH1 from Christchurch had been closed off and existing stockpiles were seeing increased usage. This was initially relieved by transporting fuel from Nelson, however the SH63 alternative route eventually restored the supply from Christchurch. Maritime and rail transport have been excluded from this analysis as there was little to no interaction between these modes and the towns we have investigated.

3.3.2 Three Waters Networks

‘Three Waters’ consists of water supply, stormwater drainage and wastewater. These systems were impacted to varying degrees across Marlborough and North Canterbury (Hughes, et al., 2017). The 2013 Seddon earthquake had prompted the replacement of older water supply well systems for increased resilience, leading to generally greater survivability among these specific replacements (Hughes, et al., 2017). Older storage tanks in the rural water supply networks of Ward and Seddon collapsed, although newer models performed well. The connections between tanks and water pipes tended to suffer significant twisting and failure, even with modern AC piping and tanks while older brittle piping damage was largely localised to specific soil types (Hughes, et al., 2017). Hughes, et al. (2017) identifies interfaces between structures (e.g., bridges, tanks) as vulnerable points in a modernised water supply network.

During the 2013 Seddon and Lake Grassmere earthquakes, Seddon lost three potable water tank farms and after the 2016 Kaikōura earthquake, readings from these electronically monitored tank farms suggested that they were empty. Onsite teams soon discovered that the tanks themselves were intact, however they had been thrown off their fittings by half a metre, which required significant repairs. Most mains breaks were repaired within two days by a company contracted to manage the Seddon water supply, although it took between a week and ten days to fully repair all water mains breaks. A notable pattern arising in wastewater systems in the 2013 Seddon earthquake is that pipes running east-west suffered damage while those running north-south were relatively unscathed. This pattern was not recognised following the 2016 Kaikōura Earthquake (Hughes, et al., 2017). Residents boiled water from the town supply to avoid possible contamination (Marlborough District Council, 2017)

Seddon wastewater uses asbestos cement (AC) piping, which carries sewage to treatment ponds before being discharged in to Starborough Creek. The AC piping only had minor breaks following the Kaikōura earthquake, however there was concern that hairline fractures from the 2013 earthquakes would rupture completely as the piping had a similar strength to earthenware. Some sewage was found to be leaking, however exfiltration and infiltration effects from earthquake damage are not covered by CDEM recovery funding rules so these could not be immediately dealt with. As e. coli levels increased, coastal no-swimming signs were installed in several swimming areas as a cost-effective solution to maintain public health until the leaks were fixed.

Ward has two community owned and operated water schemes, both of which were heavily damaged. All the pump stations fell off their pedestals, and there were multiple breaks throughout the schemes. A critical power pole fell over so no power was getting to the water network. Roofs of tanks on the hill collapsed and most had cracked walls. The earthquake had also caused major breaks in the pipeline to and through the town. These outages highlighted the ethical dilemma of public resources being brought in to manage essentially private assets or leaving residents without water. Two locals self-repaired the water schemes to partial effectiveness, prioritising this over even their own farms, however it would not be able to perform well under aftershocks or heavy rain events. Most of these non-council schemes aren't treated, which makes them especially susceptible to contamination. Emergency water rations were distributed at the Ward town hall, and supervised showering facilities were installed nearby by the New Zealand Defence Force. Ward tanks that collapsed in the earthquake were eventually replaced with new plastic tanks purchased by MDC. Most people in Ward relied on septic tanks for wastewater.

3.3.3 Electricity Network

The electrical network feeding our small towns is split into three main parts. The transmission line, operated by the state-owned entity Transpower, transmits electricity from generation stations to grid exit points (GXPs) around the country. From here, distribution networks run by private operators distribute power to homes and businesses. Marlborough and North Canterbury each have different distribution networks and operators.

3.3.3.1 Hurunui

For the first 48 hours following the Kaikōura earthquake infrastructure managers followed a 'find and fix' mentality, patrolling lines and assessing if individual buildings were safe to energise. This is essentially a business as usual approach as lines are often being patrolled, however now helicopters were assisting the search. 7000 customers were initially out of power, dropping to 2000 within 24 hours and hundreds within 72 hours. All customers were reconnected by Christmas 2018.

Three Waters infrastructure and 'sensitive loads' (hospitals, etc) are typically first priority for re-establishing power. Communications infrastructure is also a high priority for power restoration. These priorities are interrupted by geographical or infrastructure co-dependence constraints, where it would make little sense to simply wait for access to high priority infrastructure access when lower priority infrastructure is accessible and can have power restored. There is also a priority hierarchy based on significance, for example Culverden lost power due to transformer failure at the substation feeding it, but lines feeding this substation and others were down elsewhere so it made little sense to fix the Culverden substation before the other lines. Core infrastructure needs to be restored before others can even be brought back online. Customers at end of the lines determine priority of specific infrastructure. Critical buildings such as hospitals are included in this definition, however if the occupants are being evacuated long-term then building priority will drop. It is important to note that hospitals and other such critical buildings are likely to have a diesel generator onsite in the event of power outages, however fuel supplies to support this will run out quickly if there is poor access to the building from blocked roads or building damage. If there are no other competing priorities, restoration is selected based on numbers – half an hour's work that restores 30 people will be preferred over half an hour's work that restores 5 people. Fulcrum GIS is used to track the status of assets.

It is therefore critical to the decision-making process that accurate information on the status of infrastructure is being supplied to distributors, and that up-to-date records on customer use and distribution are available. Communication was difficult with some areas, especially Kaikōura, inhibiting the transmission of information about the status of infrastructure – therefore delaying and/or impairing decision-making. This increased the priority for restoring electricity to communications infrastructure, although some radio towers had battery backups available for short periods of electrical outages.

Substations experienced little damage from the earthquake. Most damage to the electrical network appeared to result from ground movement directly shifting and destabilising poles, trees falling into conductors and landslides burying and pushing over poles. Subsidence was a further hazard. Access to infrastructure often proved challenging. Authority is needed to enter property, while physical access can be impaired by livestock or obstacles. Transport of materials and equipment are each important as well, however this can be difficult where road conditions are poor – notably the Inland Road to Kaikōura. Pole infrastructure, while identified as a weakness in the network, is difficult to improve on. Some modern, pre-stressed concrete poles reportedly perform worse than simple wooden poles, and upgrading will pass costs on to the consumer. It is cheaper to simply replace or restraighten poles after an earthquake than invest in resilience in this regard.

3.3.3.2 Marlborough

There are 25,000 customers across Marlborough network, extending south to Clarence and north to Havelock. For Marlborough, the electricity network performed relatively well. Substations were tripped in Blenheim immediately following the earthquake, but were restored within an hour. Most of the damage to the network was focused towards south and east Marlborough near Seddon and Ward. Outages are tracked in real time using ESRI based GIS systems. In the field, GPS tagging of network faults was accomplished via helicopters, which fed back into company GIS. The initial assessment took three to four days, working outwards from substations along lines. The biggest anticipated challenges were aftershocks, uncertain safety of infrastructure and human fatigue. Much building resilience had already been informed by hazard scenario planning, including relocating substations, adding redundancies, installing devices to partition segments of network safely and establishing a private radio communications network. New powerline infrastructure generally performed better than older infrastructure in the earthquake, however this is more due to differences in conductor materials. As was the case in Hurunui, modern pole designs appear to increase earthquake resilience very little, and are very expensive. Aging conductor infrastructure has been identified as a weakness in the infrastructure network.

The emergency preparedness plan of the power utility, as in Hurunui, prioritises feeder restoration based on customers. For example hospitals, CDEM sites and Council sites are considered very high priority. There is a recognised need to plan for seasonal changes in electricity usage, as winemaking and tourism are such a significant industry in Marlborough. This would increase the restoration priority for important industry facilities such as wineries. Holiday homes are given the same priority as other homes, even if unoccupied. There is no guarantee of electricity however, as generation and long-distance transmission is reliant on the nationalised company Transpower. Most customers were restored within a week.

3.3.4 Communication Networks

Telecommunication networks in North Canterbury and Marlborough consist of landline and wireless infrastructure. The landline network connects local exchanges through both suspended and buried cables. Most landline damage was associated with buried cables, which were stretched and twisted by transient ground motions (Giovinazzi, et al., 2017). The displacement of bridge components also contributed to warping damage, an example of compounding infrastructure impacts (Giovinazzi, et al., 2017).

The wireless network consists of cell sites, radio/cellular towers and mobile switching centres (Giovinazzi, et al., 2017). Many of these are dependent on landline infrastructure to feed data, notably national fibre networks. Wireless mobile networks experienced outages in the 2016 Kaikōura earthquake largely due to power cuts (Giovinazzi, et al., 2017; Liu, et al., 2017) and while the wireless repeaters of independent radio communications were damaged by the earthquake, this did not disrupt communications in all instances (Giovinazzi, et al., 2017). The Inland Road/Route 70 between Kaikōura and Waiau, following formerly underused roads, has been identified as a blind spot in the public communications network. Access to the mobile 4G network here is severely limited, meaning that travellers lacking satellite devices are vulnerable to long-term isolation in the event of a vehicle accident or road blockage (Dangerfield, 2017). Mobile network access was also limited along the alternative Christchurch to Picton route, which saw a sudden increase in both freight and visitor traffic following the earthquake (NZ Transport Agency, 2016; Wotherspoon, et al., 2018).

CDEM and local government have a high reliance on radio communications to broadcast emergency information, but now that radio stations have become more centralised it has become difficult to broadcast after hours. Many of these rural communities have very poor radio communications capacity and often receive high-power broadcasts from outside the district. In the United States it is mandatory for stations to be co-opted by emergency management, but this is not applicable in New Zealand. Brian FM, an advertisement free radio station, offered to function like this so that Marlborough CDEM only have to 'flick a switch' to broadcast live information. Brian FM have been improving their network across the region, planning to spread coverage into the Marlborough Sounds and along the East Coast. Coverage as of December 2018 is depicted in Figure 3.6. There is now a need for Marlborough CDEM to actively publicise that this will be the radio station with the earliest information broadcasts, as the music playlists cater to a more niche audience than popular stations. Brian FM was the first station on-air after the Kaikōura earthquake. Some broadcast sites had backup power generators, however following this earthquake AMI Insurance sponsored a generator for Brian FM's main broadcast tower.

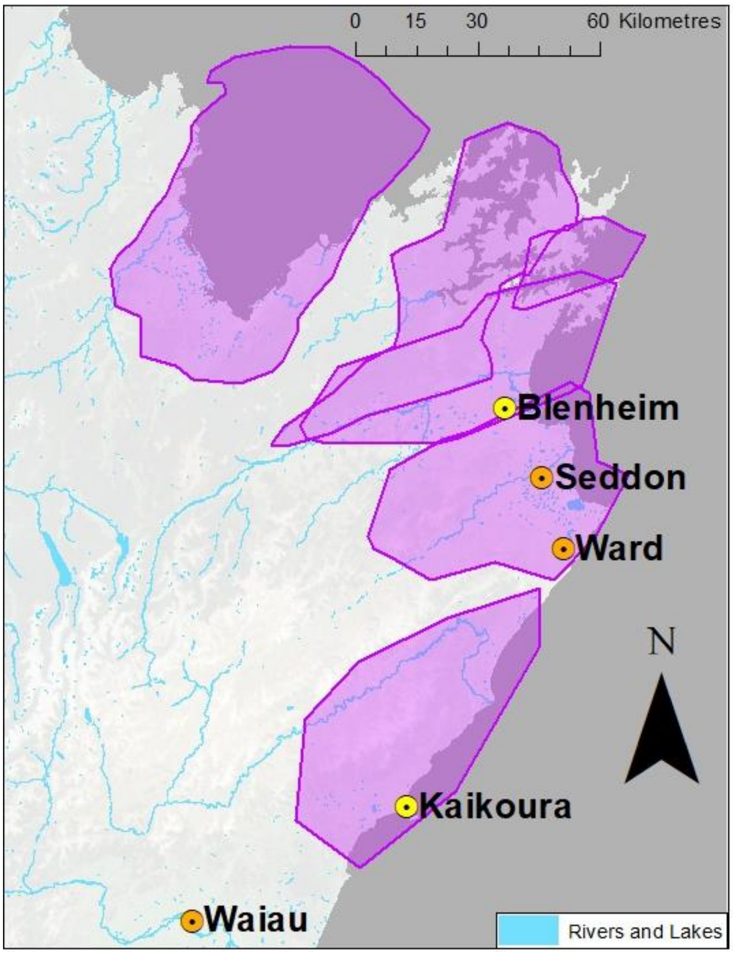


Figure 3.6: Coverage of Brian FM radio broadcasts in Marlborough and North Canterbury. Adapted from http://brianfm.com/Coverage-Map/

There are some places in the Awatere Valley and a few islands in the Marlborough Sounds which lack radio coverage altogether, even during business as usual. Mobile networks were unreliable following the earthquake, so satellite phones and VHF radios were used extensively for contact. While broadcasted telecommunications were brought back online fairly quickly, it took much longer to repair underground cable telecommunication infrastructure.

3.3.5 Critical facilities

The Lake Grassmere Saltworks occupy one third of Lake Grassmere, just east of the Seddon township. While one access road was damaged, the saltworks were accessible from multiple directions and it was not isolated. This is a good example of network redundancy improving resilience. In contrast, the nearby Marfell's Beach Department of Conservation (DOC) campsite was closed for two years following the 2016 Kaikōura earthquake as the single access road was blocked by debris. Access to the campsite was also affected following the 2013 Seddon earthquake.

The boat ramp and crayfish processing factory in Ward are important facilities in the chain of production for the local fisheries industry. The company which owns the factory and uses the boat ramp employs as many as 30 Ward residents, making it an important employer for the small town. Uplift at Ward Beach rendered the boat ramp dangerous to use. The rocky seabed there is significantly shallower now, and at the time of writing in January 2019, the crayfishing company still cannot launch boats as often as they could before the earthquake. There are ongoing discussions to move the site further north up the beach, however this has seen considerable opposition as the proposed launch site borders a marine reserve. The processing plant was also damaged in the earthquake, leading to the disposal of stored crayfish. Strong winds brought in by the 2016 November/December heavy rain events damaged vineyards. While farmers are typically resilient enough to absorb the impacts of a bad year by preplanning for adverse weather, they will need assistance when multiple events occur across successive years.

Each of the four case study towns have a school within their township. Such small, rural area schools commonly need to teach multi-level classes with children of various age groups

– reflecting the low rural population serviced (Stockton, 2016). Physical damage to schools was limited the 2016 Kaikōura earthquake. Schools served as information dissemination facilities, with teachers promoted as official sources of news and recovery updates. With usual communications channels shut down, parents are able to use school visits as a way to discuss their issues and “swap war stories” with other parents. Schools can also be therapeutic for children, who can share their experiences with peers and leave the often stressful conditions of home.

Community or town halls are an important focus for close knit rural towns. These were impacted to varying degrees by the earthquake, depending on proximity to the earthquake and building materials, however even when damaged the location continued to be a meeting hub for the community. Aid was often distributed from town halls, the land of which also played host to temporary facilities such as emergency shower blocks. In cases such as Waiau, the town hall property was used as a site for temporary emergency accommodation soon after the earthquake. In Ward, a makeshift welfare centre was set up at the local community hall, giving at least 22 people temporary shelter and access to supplies (Newton, 2016). Some visitors to this welfare centre were tourists air-lifted from campervans north of the town (Stuff, 2016). Barbeque events were common, doubling as community meetings.

3.3.6 Dwellings

A typical farm hosts a homestead dwelling and several sheds and outbuildings for storing equipment, vehicles and stock. Farmers tended to do work around their farms before attempting self-repair of their dwellings. Township properties on the other hand are packed together in higher density blocks, usually consisting of a single dwelling in each lot. Lower average incomes in these areas mean that new developments are uncommon in rural townships, leading to a high proportion of dwellings built under outdated earthquake standards. Old brick-and-mortar buildings without the benefit of seismic retrofitting did not perform well, however modernised low-rise infrastructure only suffered minor damage as expected (Dizhur, et al., 2017). An exception to this rule were the log cabins at Mt Lyford, which were top heavy and tended to shift off their foundations. One such dwelling collapsed, resulting in death for an occupant. Building codes for log dwellings specifically have been improved in the wake of the earthquake. The capacity for small towns to upgrade their buildings contributes to infrastructure resilience, and this is identified as an avenue for further research.

3.3.7 Building Inspections

There are stark contrasts in building inspection methodologies between the Marlborough and Hurunui districts identified in this thesis. Different levels of government oversight, adoption of new technology and doctrine flexibility result in unique challenges and advantages for each building inspection team.

3.3.6.1 Hurunui

There were three phases to Hurunui building inspections:

1. Rapid assessments: Establishing red zone, took one day
2. Recovery: Inspecting buildings to placard, took three and a half weeks
3. Post recovery: Placards expire, buildings reassessed and replaced with 'dangerous and unsanitary notices (124 notices), took a further three and a half weeks

Domestic access to lifeline services are investigated and recorded as part of an inspection. Technically the loss of water supply to a dwelling constitutes an 'unsanitary or dangerous' building.

In Hurunui a 'Red Zone' was established, within which the majority of severe damage was thought to be contained. Around 3500 commercial and residential buildings needed to be inspected within the Hurunui Red Zone, with a five-person inspection team, so additional inspectors were requested from Canterbury Civil Defence Emergency Management Group (Canterbury CDEM Group) – with limited success. Neighbouring districts were prepared to send additional inspectors but could not without the Canterbury CDEM Group's approval. There was a notable disparity between the 1500 qualified building inspectors nationwide and the CDEM Group's inability to fill the district's request for 40 additional inspectors, identified by some interviewees as a product of bureaucracy in a busy situation.

On the second day following the earthquake, Hurunui inspections began. There was very little administrative preparedness. Although GIS mapping was available for central organisation, electronic integration was limited with most inspection reports being submitted on paper. Additional staff were hired to input this information into computers. The following placards were designated to buildings in the Hurunui District:

- 74 red (unsafe),
- 250 yellow (some rooms safe to occupy),
- 3275 white (safe to occupy, not necessarily free from damage),
- 96 other (cannot enter, cannot find or inspection refused).

This placard colour scheme differs from that used in Christchurch and Marlborough in that green is substituted for white. The reasoning behind this is that Green placards can give the impression that a residence is free from damage and does not require further attention. Of the 'other', or lack-of-placarding category, one resident refused inspection for weeks until officials successfully negotiated with his lawyer. The resident was fearful of being removed from his home should it have been allocated a red placard.

Normally only 2000 inspections a year are carried out in Hurunui, so 'normal' non-earthquake inspections and consents needed to be put on hold. The frustrations of 'normal' consent and inspection clients were noted to grow over this time period, as only half of Hurunui District was experiencing emergency conditions. Some interviewees suggested that three and a half weeks was deemed dangerously long to conduct inspections, as this meant some people were occupying potentially unsafe homes during aftershocks. Most properties were accessible by road at some point in the three and a half weeks, however some still required access by helicopter. To help ease living situations over this time, the inspection rules were modified to allow rural people to move out of damaged houses and into structurally sound sheds and other buildings on their property. This was especially important for farmers who often have other dwelling options and needed to tend to stock on location. A further distinction from Christchurch building inspections is that a welfare officer was not attached to each inspection team in the Hurunui inspections. It was deemed impractical for welfare officers to stay behind at each dwelling for a short time to discuss options with residents, as there is significant distance between rural homesteads and thus large travelling times. Welfare forms were distributed by building inspectors instead, to be filled out and request further support if needed. Building inspectors also monitored and reported back welfare requirements.

The workload of reassessing placarded buildings following the recovery period had not been planned for, again taking three and a half weeks. At the time of interviewing (July 2018), 60 buildings continued to hold 124 notices (not safe to enter).

Culverden placards totalled four red and five yellow, while Waiau included 22 and 15 respectively. Most damage occurred from Culverden northwards, matching modelled and recorded ground motion intensity.

3.3.6.2 Marlborough

The vast majority of Marlborough's rapid assessment was completed within 24 hours of the earthquake. Most damage had been localised to the south eastern Marlborough area with the Kaikōura earthquake, which is a similar damage pattern to the previous 2013 Lake Grassmere and 2013 Seddon earthquakes. There was typically more damage to heavyweight buildings, such as residential structures with brick cladding and commercial unreinforced masonry, with most properties south of Seddon experiencing medium to severe damage. Many previously standing heavyweight buildings in south Marlborough were already removed following the 2013 Seddon and Lake Grassmere earthquakes, leading to fewer required assessments in 2016. The Ward community hall experienced little damage in 2016 due to its lightweight timber construction. Similarities exist between Christchurch and Marlborough in terms of areas with high liquefaction susceptibility. This redirected MDC's long-term plan for increased development from a southern focus to a northern focus following recent earthquake events. Some isolated, unofficial red zone areas in south Marlborough have been identified, where building damage was significant but evacuation voluntary.

The Rapid Response GIS system was software for use on handheld tablet computers that allowed responders to catalogue buildings visited and automatically upload additional information to a central GIS repository, with a real time updated screen at headquarters. The software Survey 123 was implemented as part of this. This electronic system worked well even without mobile internet signal, as the software would store data until communications could be restored again. By the second day following the earthquake, rapid response teams were readied with target areas identified by the previous day's rapid assessment. Ward and Seddon building inspections were mostly completed within the first week. Integrated GIS was invaluable in locating remote buildings across more rural areas of the district. Digital placarding followed the Ministry of Business, Innovation and Employment (MBIE) template, however as a declaration of emergency was not issued for Marlborough, the Building Act was still in power. Placards are not typically used under the Building Act, yet a need for a placarding system was recognised – both for the benefit of response personnel and to reassure the public. As of August 2018, MDC were engaged with MBIE to assist in the development of a system specifically for situations without a declaration of emergency. This maintains local powers, allowing MDC to respond immediately without waiting for affirmation from CDEM. While the undeclared system in place for the Kaikōura earthquake response had its advantages, there was reportedly some frustration from certain teams or groups that MBIE communication channels were limited. The biggest issue was communication on the go as many cellphone towers were disabled. inReach 2-way satellite communicators (text-based) are being bought for inspection teams to use in future emergency events. They also have potential for general use in remote locations.

Many rural properties operate on effluent systems, and as it was not immediately obvious if these systems had failed. Specialists were used to assess each system. Many farmers needed to work on their farms, but the distance from temporary accommodation options in Blenheim or even local townships, and regulations about occupying alternative dwellings such as sheds and garages meant that their only practical option was to continue to live in damaged homes. Some parents stayed behind to work while other family members resided in Blenheim. In most cases however, families continued to live in broken homes. Emergency housing was very limited, with only three units being relocated from Christchurch for use in a recovery village.

The Building Act usually states that consents need to be processed within 20 days, however consents marked as building repairs were accelerated as soon as possible. As in Hurunui, people were requesting normal consents during this time too, so the increased workload introduced new challenges. There were discussions about what was able to be done under Schedule 1 (building works without consent) for residential and industry in order to facilitate quicker self-restoration of damaged infrastructure. In response, building inspectors distributed booklets outlaying what people could do under schedule 1 maintenance and repairs – both for residential and business.

Dam engineers needed to be sent to investigate if artificial dams needed dewatering as with the 2013 Seddon earthquake. Landslide dams were also a cause for concern, resulting in some houses downstream being given a yellow placard due to limited access (i.e. only habitable during daylight hours), despite no structural damage. One such dam cleared itself during the large rain events in November and December 2016. The rain caused further problems in the days following the earthquake, with some placard status requiring revision. One such example was of a house marked habitable after the earthquake, but then downgraded to a red placard after being damaged by flooding. Most placard reassessments were carried out on commercial buildings, however we do not have information for why this is the case.

3.3.8 Interdependencies

Broken bridges across North Canterbury and Marlborough represent pinchpoints for lifeline services (Palermo, et al., 2017), including but not limited to electrical distribution networks, fibre communication cables, water supply piping and transport in the form of roads, rail and pedestrian access. For this reason, the strength of bridge infrastructure has significance across many different lifeline services, and thus is involved in the emergency planning of several sectors (Canterbury Lifeline Utilities Group Meeting 2018, North Canterbury Lifeline Utilities Group Meeting 2018).

Culverden is considered a farming 'hub' for the Amuri Basin (Hurunui District Council, n.d. a). As the traditional centre for business in the area, Culverden represents a critical link in the chain of production for rural industry in the Hurunui District (Hurunui District Council, n.d. a). As a nearby farming community, Waiau is very reliant on the maintenance of the main road link connecting to Culverden, which was heavily damaged by slips and surface rupture in the Kaikōura earthquake (Stuff, 2016). As Culverden is host to the dairy distributor Fonterra's only milk processing plant in Hurunui (Fonterra Limited, 2015), this increases the stakes for dairy farmers who must continue milking their herds throughout emergency response and recovery (Stuff, 2016). Although Fonterra guaranteed to pay a base rate for milk which could not be transported, this milk still needed to be dumped which can cause environmental degradation and long-term issues for pastures. With the rapid restoration of roads and bridges in Hurunui, Waiau and Culverden dairy farmers did not need to dump milk – unlike some dairy farmers along the Inland Road. This is an example of interdependency between communities, facilitated by lifeline service infrastructure.

SH1 south from Seddon became an important route for the transport of relief supplies and for lifeline management vehicles to access several east coast communities (Stuff, 2016). Being the only overland route from the Marlborough district, the closure of SH1 through gorge and gully pinchpoints in the hilly terrain north of Seddon represented a critical failure of the transport network. As the timely reopening of this road through Seddon depended on local volunteer availability, Seddon may be considered a critical area for recovery upon which other settlements depend upon.

3.4 Wider Discussion

The built environment is only one facet in determining resilience. Socioeconomic factors can equip communities for success or failure, and drive many of the secondary impacts to a community following lifeline service disruption.

3.4.1 Socioeconomic Response

We see similar socioeconomic stratification across each of our case study communities. Typically farmland is inhabited by wealthy families who run their rural business from home, whereas lower socioeconomic demographics are attracted to the cheaper property prices and rent of the townships. A weaker financial position restricts options for recovery and developing resilience. Lower incomes lead to reduced capital for building resilience within the home or business – inevitably creating locations that are highly vulnerable to disruption. Such low investment in resilience was exacerbated by the earthquake as insurance was often poor, leading to small payments for recovery. In the case of one family, the insurance payout was lower than the cost to simply reconnect utilities – let alone fund the reconstruction of their home. Such low payouts were sometimes not used in rebuilding, instead being spent on debt or entertainment. There were some reported cases of predatory pricing for tradesmen which did not help this situation, particularly in remote rural locations. Poorer families who could not safely inhabit their homes would also need to commute for some time between jobs and temporary accommodation, whereas many farming families would have land and additional buildings for temporary habitation on their own property even when the main home was unsafe. Farms are businesses, so despite higher capital in farming families, much of this is invested in maintaining industry in which failure has flow on effects for the wider community. The most direct of these is the employment of township residents. Well managed businesses weathered the earthquake well, however poor or delayed decisions lead to challenges. Many businesses in coastal communities had unrealistic expectations for the arrival of tourists and supplies in the coming tourism season. The idea that "some higher power" would solve their problems was common and for these reasons many did not make wise business decisions in the wake of the earthquake, electing instead to wait for instruction or consuming resources with a 'business as usual' mindset. These complex social issues are difficult to solve, however greater research into these dynamics may guide policy on improving empowerment in a fair way, without side-lining supposedly 'advantaged' people who are facing their own challenges.

3.4.2 Phases of Mental Wellbeing

We see a similar four-phase pattern of psychosocial recovery as described in Section 1.5 repeated across our interviews. It has been observed that the phases have no discrete transitions.

Seddon experienced comparatively little physical damage following the Kaikōura earthquake compared to other towns, leading to a shorter recovery period and faster progression through the altruistic and optimistic phases of this model. It is also believed by the experts interviewed that exposure to previous recoveries, specifically the Seddon and Lake Grassmere earthquakes, gave experience which further accelerated this progression. Veterans of the Christchurch earthquakes who had relocated to the North Canterbury and Marlborough regions were especially impacted emotionally, which is consistent with other research into psychosocial responses to successive disaster events (Slovic, 2000). In their own case study of the 2008 Wenchuan earthquake in China, Xu et al. (2000) attributes this to reduced self-perceived resilience in the face of future events. Low self-perceived resilience hinders actual resilience as fear and hopelessness dominate, leading to rash or poorly informed decisions. This can be a deciding factor in whether businesses fail, and can stunt household progression back into a sustainable lifestyle. My thesis does not attempt to diagnose whether this rapid progression is due to realistic stoicism or conversely reduced emotional resilience among survivors, an aspect of post traumatic stress disorder (PTSD) (Xu, et al., 2016), or a combination of these – this is outside the scope of my study. I see this is an avenue for future comprehensive research in a similar vein to Xu et al. (2016). It should be noted that some residents may skip or even regress to previous phases depending on their situation.

3.4.3 Transient populations

There was a very high number of tourists and itinerant farm workers in Marlborough at the time of the earthquake. This was due to the summer tourist season, as well as the many vineyards in the area employing seasonal labourers. While the international response to the earthquake was generally helpful, the understandable fixation of other countries on extracting their tourists and workers conflicted with the Coordinated Incident Management System (CIMS). The CIMS model expects international assistance to be given to the governing authority, rather than a series of independent operations. The prompt relocation of these transient populations did help earthquake response and recovery however, as this resulted in decreased resource use in sensitive areas.

Many seasonal itinerant farm workers, immigrants and tourists speak limited English, and for this reason councils and transport organisations have been active in distributing emergency and travel advice in multiple languages. Effective information dissemination is made increasingly difficult with rapidly changing demographics and few resources. In

Culverden, as many as 25 different languages are now spoken. Resources on the Kaikōura earthquake response and recovery were distributed in multiple languages, and labourers were encouraged to share information with each other and their families.

3.5 Governance of Risk and Resilience

Strong governance during earthquake response and recovery is critical for the long-term wellbeing of affected communities. Opportunities for governance occur at the levels of national government, local authority and interpersonal relationships.

3.5.1 Legislation

Three key pieces of legislation were passed following the Kaikōura earthquake. First was the Civil Defence Emergency Management 2016 Amendment Act, amending a month-old amendment of the Civil Defence Emergency Management Act 2002, in order to bring forward certain provisions of the recent amendment for use in the Kaikōura earthquake (Brownlee, n.d. a). These provisions supported a smooth transition between response and recovery phases, as well as establishing an authority to manage crown funding in civil defence emergencies. The second of these was the Hurunui/Kaikōura Earthquakes Emergency Relief Act 2016, which relaxed certain resource constraints, facilitates emergency actions undertaken by rural landowners and empowers the repair of Kaikōura's harbour (Brownlee, Hurunui/Kaikōura Earthquakes Emergency Relief Bill, n.d. b). The third key piece of legislation was the Hurunui/Kaikōura Earthquakes Recovery Act 2016, officialising transition from response to recovery in the main areas affected by the earthquake (Brownlee, n.d. c).

3.5.2 Clarence and Kekerengu Jurisdiction

Clarence and Kekerengu are two especially small communities along SH1 north of Kaikōura, both under the jurisdiction of Kaikōura District Council (KDC) (Figure 3.7). They were temporarily brought under the jurisdiction of MDC shortly after the earthquake. Ground access was inhibited from the rest of North Canterbury to these communities, whereas SH1 was still traversable in the opposite direction back towards Marlborough. MDC services were extended including the delivery and clearing of rubbish skips in each of the townships, one of which was stationed at Clarence School. Existing contacts between Clarence, Kekerengu and MDC helped to facilitate the relationship.

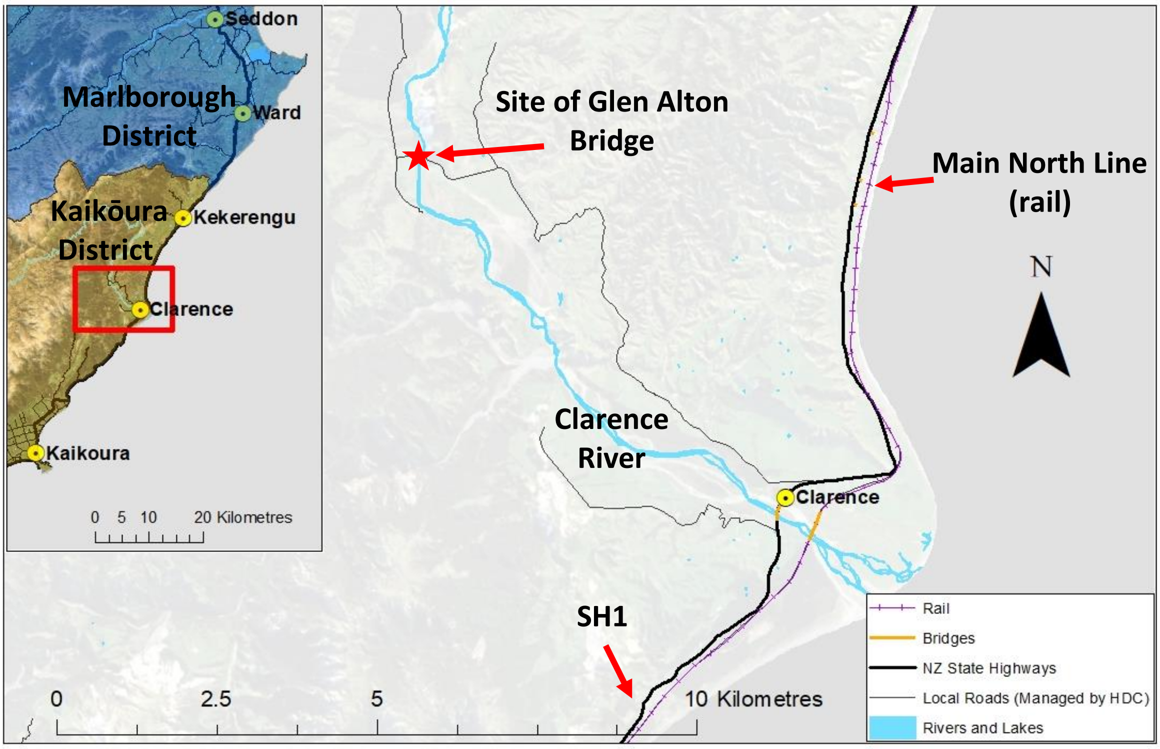


Figure 3.7: Clarence and the east coast.

The Clarence township has become well known since the earthquake, most notably as Glen Alton Bridge access has yet to be restored (Figure 3.7). Residents and recovery personnel adapted to this disruption by fording a stream south of the crossing, however this option limits access to high-clearance 4WD vehicles and is frequently unusable in adverse weather conditions. On 21 December 2018 Kaikōura District Council (KDC) announced that six replacement options for Glen Alton bridge have been evaluated (Kaikōura District Council, 2018), however this complex issue has already left the future of Clarence residents in a state of uncertainty for two years. With a significant rise in rates to fund the Kaikōura rebuild and long-term politics over regional governance, our interviewees report that there is sentiment in favour of returning to MDC jurisdiction permanently.

3.5.3 Data management

Inter-organisational sharing of information was inconsistent across the study area. In many cases, red tape from commercial sensitivity and confidentiality kept councils from coordinating their efforts with infrastructure managers and government agencies. This had an additional impact on community morale as homes would be visited several times by different organisations asking the same questions. The lack of coordinated information sharing can lead to serious issues. For example, the Ministry of Social development was unable to share information about potentially high-risk or antisocial individuals, putting both doorknockers and those residents in potentially adverse situations. The MDC adapted to this issue by asking residents to sign information consent forms, allowing MDC to request relevant information directly from other organisations. A common database was subsequently set up for Marlborough organisations to facilitate sharing, although earlier establishment would save time and resources in future disasters.

3.5.4 Engagement with communities

As part of their efforts to encourage engagement with local communities, HDC mobilised a 'welfare campervan'. This vehicle toured campsites and major public areas disseminating information, while giving residents an avenue to voice their concerns and request assistance. While this initiative was useful for those who responded, participation was very limited.

'Support Navigator' is a role developed by the Primary Health Organisation (PHO) with the broad remit to facilitate communication between rural communities and support organisations. Up to ten navigators have been appointed across Marlborough, Kaikōura and Hurunui (South Island CDEM Conference, 2018; MCDEM, n.d.). Support Navigators assist locals to access support programs for health and insurance while also giving the providers of these programs feedback on where and how to most effectively direct their efforts. Many of these small rural communities are not only physically remote, but socially too, so this kind of outreach seeks to connect people with outside help through trusted members of the community. For Kaikōura and Hurunui, the top four presenting issues were financial hardship, awaiting insurance scopes of work, a need for independent insurance advice and living in uninsured, damaged homes (MCDEM, n.d.). For Marlborough, winter home heating and insurance were the main issues reported (MCDEM, n.d.). These channels have also proven effective in disseminating information from the community through a trusted source.

3.5.5 Naming of the earthquake

As summarised in the literature review, many of those living outside of Kaikōura felt that they were being side-lined by the naming of the earthquake. Media attention was interpreted as being directed towards Kaikōura and quickly stuck. Renaming the earthquake in the popular consciousness quickly became impossible, and even attempts to reclaim it as the 'North Canterbury Earthquake' fail to represent all people within the extent of damage. Similar sentiments surrounded the naming of the Seddon and Grassmere earthquakes as well, which again impacted more than just these specific namesake areas. Identifying the point at which naming conventions lose significance in supporting disaster recovery is outside the scope of this thesis, although this appears to affect morale and compliance among affected rural communities.

3.5.6 Firefighting

The Hurunui district had been experiencing a three year drought and despite the earthquake occurring near the start of the typical rural fire season, fire hazard in Hurunui was uncharacteristically low. Two major rural fires occurred in North Canterbury in the summer of the earthquake; the February Port Hills fire in Christchurch and Hanmer Springs fires in March, 23km west from Waiau. The Hanmer fire closed State Highway 7, the road linking Waiau and Culverden north to Hanmer Springs, blocking the main alternative route between Christchurch and Picton. Although fires can be a common secondary hazard of earthquakes, likely through leakage of flammable substances or electrical arcing (FM Global, 2015), neither of these fires were attributed to damage from the Kaikōura earthquake.

There has been some concern that helicopters would not be so readily available for evacuation, reconnaissance and aid transport should wildfires occur alongside future earthquakes in the region. As many volunteer firefighters also form volunteer civil defence groups, they would be pre-engaged in other emergency management responsibilities or vice versa depending on the timing of hazards.

To supplement combating fire hazard in the future, seismogenic or otherwise, there is a mandatory requirement for every residence not connected to a reticulated water supply to have installed either sprinklers equipped with a 7000 L water tank, 45,000 L water tank without sprinklers, or a third alternative option that must be negotiated with HDC and Fire and Emergency New Zealand [FENZ] (Hurunui District Council, n.d. b). Alongside this intended use, these tanks potentially double as potable water sources for remote dwellings, improving resilience to drinking water supply issues. While these dwellings are by definition not on a reticulated council water supply and thus not directly impacted by a loss of the service for drinking water, a large tank of safe drinking water lowers the need for supplementary deliveries – freeing up resources to be used elsewhere.

3.6 Chapter Summary

Chapter 3 assessed critical infrastructure impacts and adaptations in four small towns to answer the research objectives. The four towns are split between two districts: Culverden and Waiau are in Hurunui District, while Seddon and Ward are in Marlborough District. Seddon and Ward experienced large earthquakes previously in 2013 (Seddon and Lake Grassmere) which increased physical resilience in that many vulnerable buildings had been removed, replaced or strengthened prior to the 2016 Kaikōura earthquake.

3.6.1 Roads

- Largely blocked by landslides, damage from surface rupture and lateral spreading, power poles and electrical conductors. Bridges were commonly pushed off their abutments. These impacts isolated some small communities.
- Clearing of roads soon after the earthquake assisted in rapidly reconnecting communities to important services and infrastructure repair teams and was assisted by the residents of some small towns.
- Adoption of the Inland Road as a primary roading focus hastened restoration of access to Kaikōura by road.
- Air travel was used to bypass damaged roads altogether.
- The closure of coastal SH1 isolated several small rural communities, and the restoration of this route took significant time and effort. This was improved with the creation of the NCTIR alliance of industry and infrastructure management.

3.6.2 Three waters

- Damage across and within each of the towns varied significantly, tied strongly to soil types, interfaces between structures different types of schemes and funding mechanisms in different towns. Potable water tanks also tended to fare poorly, however for more modern systems this was restricted to connective devices.
- Issues with three waters service were less apparent in areas where private potable water tanks and sceptic are the norm.

3.6.3 Electrical networks

- Tilted poles, stretched conductors and damaged substations.
- Some critical facilities have the capacity to switch to diesel generators during a power outage, however this limited by accessibility for deliveries of fuel.
- GIS software was used extensively in managing the recovery of electrical grids.
- Radio towers switched to batteries when the power was disrupted, which allows electrical infrastructure managers to be more flexible in prioritising restoration of the electrical network.

3.6.4 Telecommunications

- Lost service from the electrical grid, and buried cables were commonly stretched or severed by the earthquake. Broadcast telecommunications typically have poor coverage between small rural towns, and is also subject to hill shadow from rugged terrain. Temporary mobile signal boosters were installed along high priority routes such as the Inland Road. Tighter partnerships between CDEM groups and local radio stations are being developed to help disseminate emergency information in future events.

3.6.5 Critical facilities

- While approaches to building inspections differed between the two districts, common challenges tied to remote populations and distance were encountered. Where these were overcome with integrated electronic systems efficiency was improved. However, paper-based approaches were slow and personnel-heavy. As only parts of each district were damaged by the earthquake, business-as-usual consent and inspection requests were still coming through, which needed to be managed alongside emergency inspections.

3.6.6 Interdependencies

- Bridges were identified as significant pinchpoints for both roading and other critical infrastructure networks carried by bridge structures, such as telecommunications and water. Where bridges were damaged by shifting off abutments, this also severed networks traversing bridge spans.
- Some industries, such as dairy farming, rely on multiple communities in a production chain. A facility in Culverden processed milk for the Hurunui District, however farms on the Inland Road were unable to access this and instead needed to dump milk. Commercial losses from the dumping of milk were repaid by dairy company Fonterra for applicable farms.

Socioeconomic stratification was observed across our communities, with demographics summarised as low-income township residents and higher-income farming families. Finances were a determining factor for dwelling resilience and access to insurance for rebuilding. Four phases of psychosocial recovery identified following the 2011 Christchurch earthquake were witnessed again in the 2013 Seddon, 2013 Lake Grassmere and 2016 Kaikōura earthquakes. The intensity of each phase and speed of progression may be affected by previous exposure to earthquakes, which is consistent with examples in other countries. Tourist and itinerant workers were displaced by the earthquake, a situation complicated by language barriers and unsanctioned repatriation.

Legislation was passed following the 2016 Kaikōura earthquake which successfully improved the flow of resources and personnel in response and recovery phases. The temporary transfer of jurisdiction of small communities such as Kekerengu and Clarence from Kaikōura District to Marlborough district helped to alleviate administrative and infrastructural strain.

Improved data management and community engagement helped to improve quality of life and ensure residents received the services they needed most. New initiatives such as community navigators were proven valuable in this regard. Public perception of disasters and recovery management is identified as sensitive to media coverage, and this can have implications for community participation and acceptance of recovery efforts.

Chapter 4: Detailed assessment of impacts and adaptations following the 2016 Kaikōura earthquake in the rural town of Waiau, Hurunui District, New Zealand

4.1 Chapter Overview

While Chapter 3 approached findings broadly, looking at the differences and similarities between the towns, this chapter explores a specific small town from our study, Waiau, in greater detail (Figure 4.1). For Chapter 4 a deeper reach into the data is required to truly fulfil our research objectives of investigating how critical infrastructure in small rural towns is impacted by an earthquake, and how the community and infrastructure operators respond to resulting losses in lifeline services through adaptation. The built and social environments form the main focus, as national and district-wide governance of risk and resilience applicable to Waiau has been sufficiently explored in Chapter 3. The built environment section is dominated by impacts and adaptations to critical infrastructure, important facilities and the services they support. This is followed by a section on Social Environment attributes, notably local perception of risk and role of emergency and hazard management organisations. This fulfils the thesis research objectives by thoroughly investigating impacts and adaptations within a small town with high relevance to recovery from the 2016 Kaikōura earthquake case study.

Given time constraints, this was best restricted to a single town. Although the town of Ward scored highest on the town selection matrix (Section 2.2), we obtained a large amount of input regarding Waiau from the interviews described in Chapter 2 (Section 2.5) and this became a more attractive option for in depth discussion. The high exposure to strong ground motion, vital network chokepoints, proximity to the epicentre, fewer complications from previous recent earthquakes and general vulnerability of infrastructure contributed to heavy damage in Waiau. In addition, Waiau's location at the southern end of the Inland Road would understandably demand consideration when reflecting on recovery from the 2016 Kaikōura earthquake. I draw from Canterbury CDEM situational reports assist in constructing an accurate timeline of events.

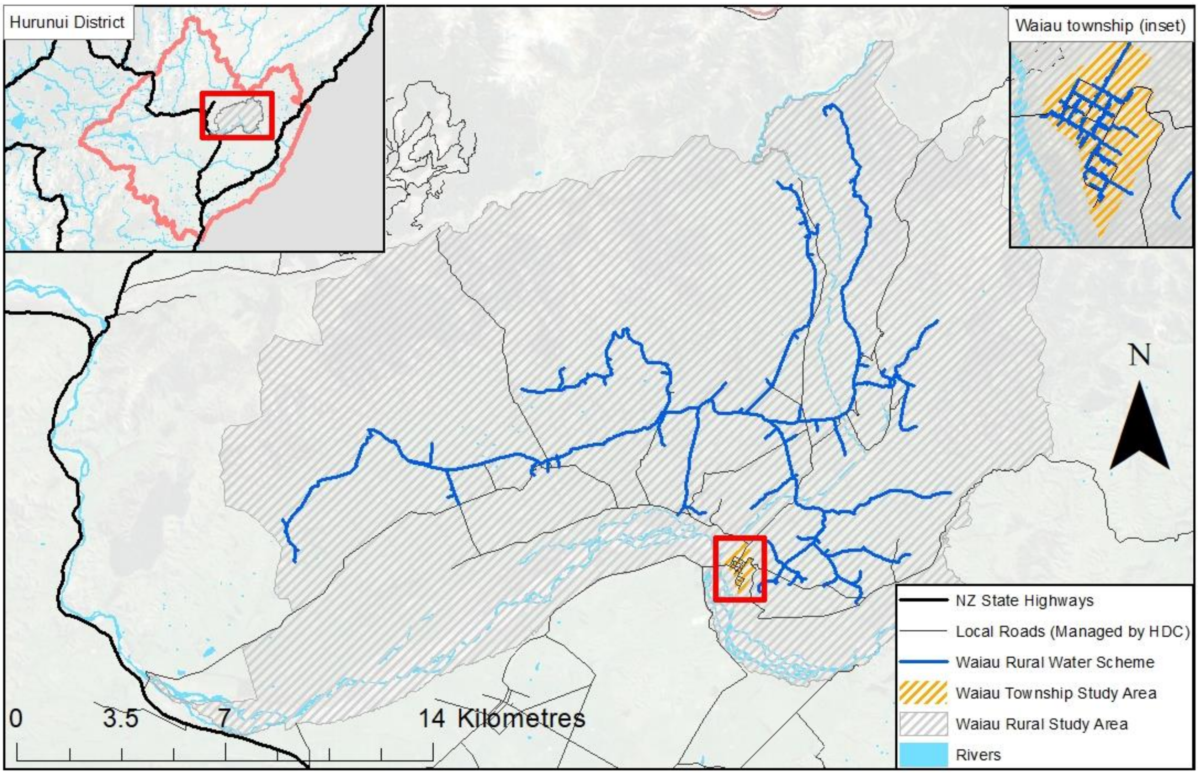


Figure 4.1: Location and extent of Waiau rural and township study areas.

4.2 Built Environment

4.2.1 Roads

Waiau township itself rests at the intersection between routes to and from Kaikōura and Hanmer Springs. This position has encouraged the township to capitalise on the role of pit stop for travellers - hosting cafes, a hotel and tourist traps such as a museum. Many roads branch out from the township to service the surrounding farmland, including a southern road which links Waiau with the nearby 'farming hub' of Culverden. Land instability and broken bridges were the biggest threats to roads in Waiau, although actual road performance was similar across all the towns (see Section 3.2.1.1). Unlike the other three townships however, all roads in and out of Waiau township rely on bridges. Each of these suffered considerable damage in the earthquake, cutting off Waiau from heavy vehicles for several days. This appears to have influenced the rate at which other infrastructure networks were repaired, notably the rural Waiau water scheme. This is discussed further in Section 4.1.8.

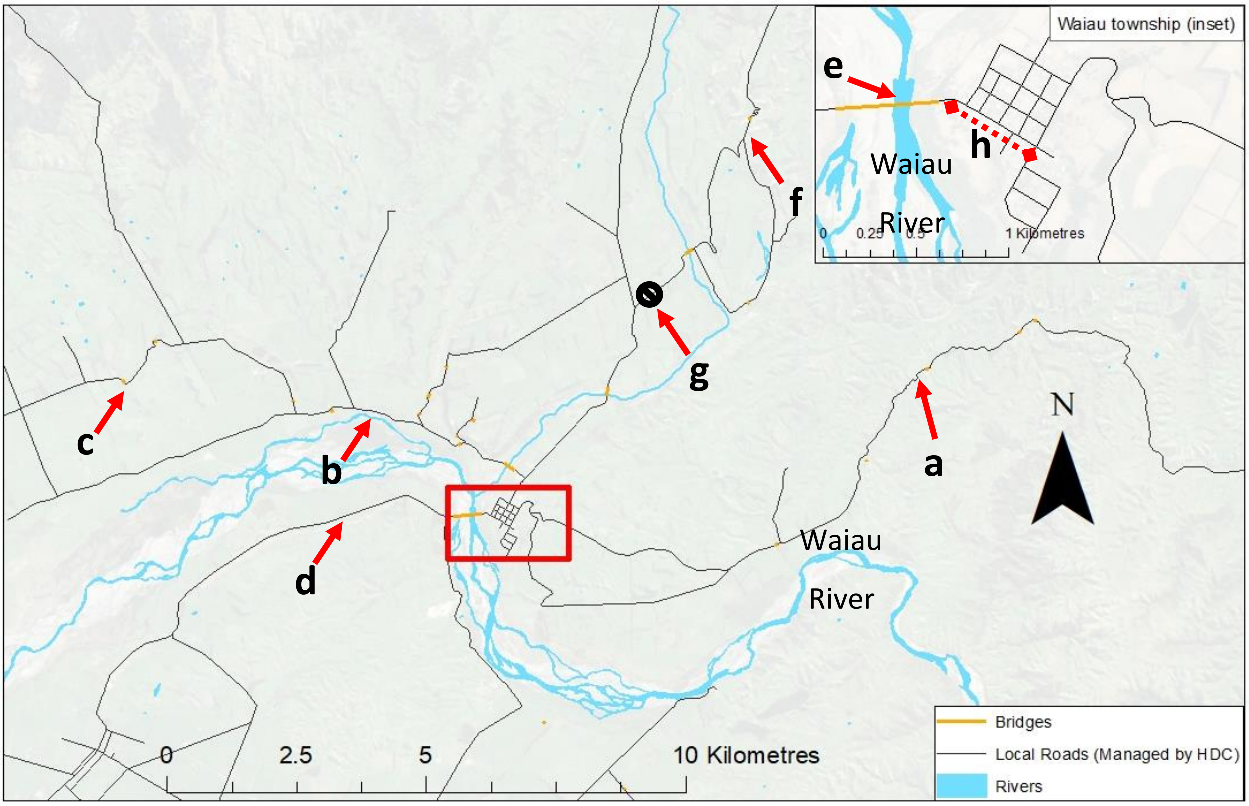


Figure 4.2: Noteworthy Roads in Waiau. (a) Leader Road, (b) River Road, (c) Leslie Hills Road, (d) Rotherham Road/Route 70, (e) Waiau Bridge, (f) Inland Road/Route 70, (g) Inland Road Cordon, (h) Lyndon Road.

The Leader Road (Figure 4.2, a) from Waiau to Cheviot is typically one of the busiest roads in Hurunui District. It connects Waiau to SH1 north of Cheviot. Combined with Rotherham Road (Figure 4.2, d), Leader Road offers an alternative route to SH7 for travellers and freight coming from Kaikōura along the coastal SH1 or vice versa. Leader Road was blocked by damage to the road from slips and surface rupture. Six different work teams were restoring the road at once in order to reconnect this important route, which was at repeated risk of landslides and landslide dam failure. Traffic between the coast and Waiau needed to be rerouted south to SH7 before travelling northward again, increasing travel times. With SH1 blocked however, the demand for Leader Road was significantly reduced.

River Road (Figure 4.2, b) connects Waiau township to properties east of the Mason River. Off this road branches Leslie Hills Road (Figure 4.2, c), which in turn continues south east until it crosses the Waiau River upstream of the township. An intersection following this bridge connects the road to SH7. The River and Leslie Hills roads were obstructed by downed powerlines draped across the road, along with surface rupture and riverside subsidence. Restoring these roads required a joint effort between road and electrical infrastructure repair crews, as road functionality was required for access to fix powerlines and roads could not be restored to full use until the powerlines were restored. Road travel was hazardous and electricity to homes in the River Road/Leslie Hills area was lost during this time. Lack of access along these roads, especially River Road, delayed repairs to Waiau's rural water scheme.

Rotherham Road/Route 70 (Figure 4.2, d) links Waiau to Culverden, another town in our study, south of the Waiau River. It leaves Waiau township across the Waiau Bridge (Figure 4.2, e), arguably the most important access route into Waiau from Christchurch. Like Leslie Hills Road and River Road, Rotherham Road was blocked by fallen powerlines and surface rupture. Waiau bridge encountered the same issues as many other bridges in the area, particularly shifting off abutments and slumping.

The Inland Road/Route 70 (Figure 4.2, f) was previously known as State Highway 70 until low traffic numbers saw this status revoked. There are some politics surrounding this road, which was left incompletely sealed when downgraded and responsibility was given to KDC and HDC in the early 1990s. This shared road is important as it offers an alternative route to Kaikōura, instead of travelling along the coastal SH1, then SH7 and SH70 (Rotherham Road section) from Christchurch. The Inland Road also connects remote Waiau farmers and communities such as Mt Lyford Village to the road network. Slips from step road cuts and several bridge failures were the main earthquake impacts. The Inland Road to Kaikōura had been initially cleared and opened by the end of the first day following the earthquake, only to be closed again when NZTA took over responsibility for the route from HDC. The cordon used to control the road is marked in Figure 4.2. This change in jurisdiction is because it gained regional (and arguably national) significance as the first overland route available into Kaikōura following the earthquake. This also freed up HDC resources for repair and maintenance of other damaged Hurunui roads and bridges.

4.2.1.1 Inland Road Cordon

Several problems emerged surrounding the operation of a NZTA cordon at the Waiau end of the Inland Road. The cordon was set up very close to Waiau (Figure 4.2, g), with the intention to restrict usage of the road to infrastructure repair crews and relief vehicles on their way to Kaikōura. Most existing damage and NZTA-proposed slip danger existed further north along the road near Mt Lyford. The initial stretch of road then was considered safe by locals, some of whom lived along the Inland Road. Many of these residents had left earlier in the day (15 November 2016) to get supplies from Waiau township but were denied entry past the newly established cordon on their return, all despite having families and pets waiting for them at home. Farmers were under particular pressure as they were blocked from returning to their farms and livestock. Meanwhile, military convoys and council vehicles visibly passed through. Residents of the Inland Road became increasingly frustrated and vocal about the management of the cordon, which also impeded access for critical infrastructure managers and recovery equipment relocation at times. Anecdotes spreading about locals traversing the road safely before the second closure, most prominently the Hurunui District Mayor, further undermined the advice of geotechnical engineers and the validity of the cordon in general. As an unorthodox transport adaptation, an unofficial route to bypass the cordon over private farmland was developed by locals. This occurred outside the approval of HDC. Although disregarding the regulatory framework in place, this adaptation did relieve pressure on both the cordon management and those living on the either side of the cordon in the Waiau area. It has been suggested through interviews that cordon staff were not sufficiently trained or well informed on who they were allowed to let through the cordon, both in regard to locals and infrastructure repair teams.

4.2.2 Potable water

Waiau is supported by two water schemes (Figure 4.3), one for the township and one which services rural properties (within the rural study area in Figure 4.1). Water is pumped from the Waiau river via a gallery bore[1] (Figure 4.3, a), before being stored in a tank farm on a hill overlooking the township (Figure 4.3, b). From here, it is transferred to the township. The

[1] An infiltration gallery is a device which harvests flowing groundwater, in this case attached to a borehole near the banks of the Waiau River.

rural scheme is 120 km long. It is fed by a shallow bore (Figure 4.3, c) from the Waiau River, before being pumped to a main reservoir (Figure 3, d) for storage before distribution to private water tanks. A very high pumping pressure is needed between the intake and reservoir as this section rises continuously for a horizontal distance of 4.5 km across boggy terrain (Figure 4.3, e). Not all rural properties operate off this rural scheme due to factors such as distance, instead relying on alternative water supplies, mainly private water bores and tanks. For the most part, both of these supplies are considered branched schemes, consisting of continuously subdividing pipelines from one point source. This is different from many large city water schemes which are more circulatory. Such branching is most vividly demonstrated in the Waiau rural scheme, which is very long while only being pumped from a single intake.

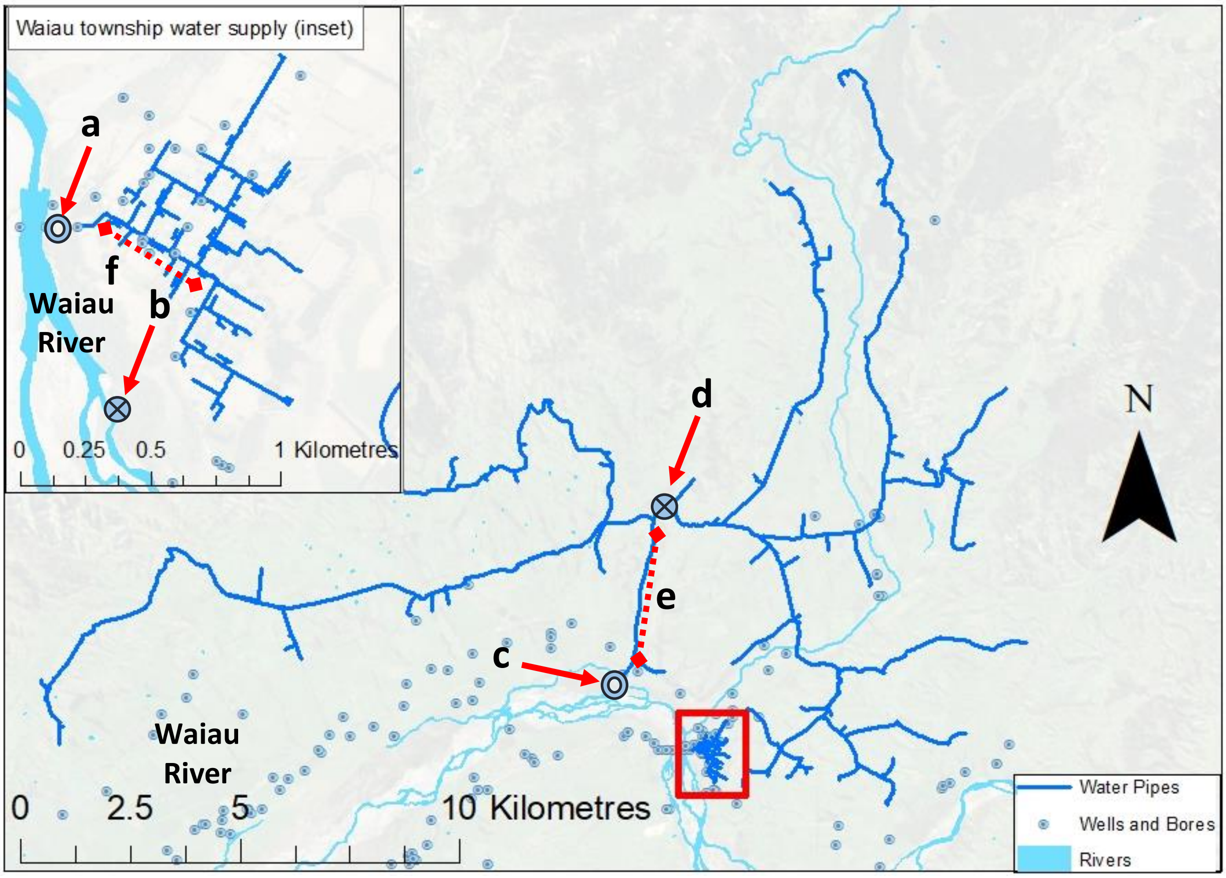


Figure 4.3: Water schemes of Waiau. Primary map shows both the rural and township supplies together, whereas the inset shows the township. (a) Waiau River intake for the township supply, (b) tank farm for the township water supply, (c) Waiau River intake for the rural supply, (d) main reservoir for the rural supply, (e) intake-to-reservoir pipeline section of the rural supply.

At first daylight following the Kaikōura earthquake (14 November 2016), physical inspection of the water networks began. Due to the road damage and blockages, quadbikes were used by inspectors to get around. A depression as long as 20 m was sighted along one part of the rural scheme, indicating damage by the earthquake. While some usable water remained in the rural scheme's pipes and local storage on farms, the township water scheme was unusable immediately after the earthquake. These cursory inspections would not be able to ascertain the true extent of damage to water infrastructure, so a district-wide boil notice was put into effect.

Water infrastructure experts from Christchurch shared advice in restoring the Hurunui schemes. However, the branching rural water supplies operate very differently to the more circulatory systems in urban areas. It is a recognised vulnerability that losing such a relatively small section of pipe can result in a very wide area losing access to water in these rural schemes. Some potable water was distributed by council personnel where needed using quadbikes, however most rural properties have rainwater tanks with at least a few days' supply, providing a redundant supply and improving resilience.

Prior to the earthquake flow meters were only present on facilities such as key pipe junctions, reservoirs and intakes, however the Kaikōura earthquake has highlighted the need for live flow information across the network. Flow meter coverage is to be expanded over the next ten years to allow for more comprehensive live data across all water supply schemes in Hurunui District. This should improve leak detection and restoration times in the future.

4.2.2.1 Town supply

Chlorine was used to treat water potentially contaminated by broken pipes. Previously, the supply was treated with UV rays before distribution (Hurunui District Council, 2009). It was soon found that the township watermain (Figure 4.2, h; Figure 4.3, f) along Lyndon Street had been severed by the earthquake. Leaks were found and repaired following an iterative process:

- Turn water main on
- Identify leak from water rising to surface
- Turn water off

- Dig up the damaged section of pipe and fix
- Repeat until no further leaks are identified

A mobile chlorine treatment plant was incrementally moved ahead of branching water mains so that the rest of the town supply network could be treated and in use while the Lyndon Street section was repaired.

The tank farm in Waiau town typically holds seven days of water, however the earthquake had twisted the tanks off their couplings, resulting in leaks, no stored water and no immediate storage capacity at the site. Three of the 24 tanks were soon restored, two for storage and a third used for periodically backwashing the system. Full tank farm infrastructure was restored within a week, however the land it occupies has since been declared unsafe due to land instability. At the time of interviewing, the entire farm still needed to be relocated (towards the east) and continues to operate on reduced capacity. It took three to four days to restore the entire Waiau township supply to usable condition. Waiau township no longer has a boil water notice, however chlorination continues.

4.2.2.2 Rural supply

An early priority in restoring the rural water scheme was to ensure transport of water from the river intake to the main reservoir. This is because both the east and west distribution branches of the scheme are fed by this reservoir. The lack of water reaching the reservoir implied significant leaks in the intake-reservoir section of pipe. Initially, three diggers were used to uncover the pipeline buried in boggy soil, which made progress slow and difficult. The pipeline was made up of 6 m lengths of asbestos pipe. These were originally installed in the 1960s. Leaks were found to be most prevalent at the couplings between each 6 m segment, as the couplings were more fragile than the pipes themselves. This is consistent with the findings of Hughes et al. (2017). The process of digging up each coupling, repairing it and reburying it was considered an inefficient use of the resources available, particularly with such aging infrastructure. To improve this, an order was made to a pipe manufacturer in Rangiora to custom-make replacement polyethylene pipes for the entire intake-reservoir section. Usually such an order would take six weeks to prepare, however the manufacturer prioritised this production for the recovery effort – dispatching the first batch within four days. In the event that the intake-reservoir section could not be restored in time, the HDC planned for installing an additional gallery intake to siphon water from a stream close to the reservoir. It took ten days to restore the rural water scheme to operational status. A permanent boil water notice is in place for the rural water supply, which also undergoes MIOX[2] treatment. Access to much of the Waiau rural water scheme was limited by obstructions on River Road and Leslie Hills Road, and could not be repaired until road access was restored.

Irrigation was a very low priority for farmers. Watering livestock was a far more pressing need, highlighting the criticality of rural water schemes for more than just human drinking water. To help alleviate this, firefighters collected and delivered water from local streams to farmers. A further adaptation made by some farmers was to remove fences along streams, providing access for livestock, sometimes across neighbouring properties. Given the circumstances, HDC made allowances for this normally illegal practice.

4.2.3 Stormwater

Most excess rainwater in Waiau either follows sub-surface drain infrastructure to the Waiau River or flows overland into swales before soaking into surrounding soil. The Waiau River has flooded before, however it is typically well-controlled by stopbanks.

An investigation into flooding in Waiau modelled that a 50 year average return interval (ARI) Waiau River flood event would be unlikely to breach the stopbanks, however the same ARI for an important tributary – the Mason River – will likely overflow through the township (Griffiths & Wild, Waiau River floodplain investigation, 2015). The November-December 2016 storms which caused significant issues for Marlborough had little impact here, however subsidence and erosion damage from the earthquake has potentially weakened Waiau River stopbanks.

4.2.4 Sewage

[2] MIOX, or mixed oxidant solution, is a method of electrolytic water sterilization utilising a solution of several oxidants, including chlorine dioxide, ozone, and peroxide among others (Quick, et al., 1999)

Waiau residents are on septic tanks rather than a centralised sewage system. There were no mass sewage outages, as failures were restricted to individual tanks. This is in contrast to centralised sewer pipes breaking in the Christchurch earthquake, after which raw sewage would accumulate at the surface with liquefaction ejecta or drained into nearby rivers and lagoons (Giovinazzi, et al., 2011). Canterbury CDEM Situational Reports suggest six cases of gastrointestinal disease, however it is not clear if this is due to water contamination from sewage, soil or some other source (Canterbury ECC Situation Report, 2016xxv).

4.2.5 Telecommunications

Waiau cell phone coverage was improved before the earthquake with the addition of a new mobile network tower in 2012. The Waiau exchange is a local landline telephone exchange operating out of Waiau town. Both mobile and landline telecommunications are supported by wired infrastructure.

Despite the relatively new mobile tower, Waiau lost all cell phone coverage. Radios therefore became crucial to communication between the council and CDEM volunteers. However, the location and use of the radios had not been effectively communicated in some cases. Temporary boosters were put in place along the Inland Route to support response and recovery as there is usually very poor mobile signal (Herbert, et al., 2018). Despite the demonstrated importance of the route for access to Kaikōura, there are no plans to install permanent coverage.

While the landline exchange in Waiau was not damaged, lines connecting to it were. These fibre cables were replaced on 16 November 2016, only two days after the earthquake after materials were transported in by helicopter (Giovinazzi, et al., 2017). Bridge crossings have been identified as common weak points in the wired telecommunications network during the Kaikōura earthquake, as different relative movements between the bridge and cables mounted on land result in stretching and snapping of cables (Giovinazzi, et al., 2017).

4.2.6 Electricity

The transmission network in Hurunui runs north-south, bringing power to the Culverden grid exit point (GXP). As mentioned in Section 3.3.3.1, this GXP feeds a sub-transmission line which powers Kaikōura. The Culverden GXP also feeds the distribution network that powers Waiau and much of Hurunui. When the Culverden GXP and Culverden-Kaikōura line is down for maintenance, power is rerouted along a series of coastal sub-transmission lines from the Waipara GXP further south, northwards along SH1, ensuring supply for Waiau by cycling it back along the Inland Road (MainPower, 2017).

The Culverden GXP failed in the earthquake. Due to extensive damage across lines in northern Hurunui and Kaikōura, power could not be delivered from the Waipara GXP. Waiau and the Inland Road lost power immediately following the earthquake. Significant damage was reported north of the Waiau River, with gradually less damage southward. Electricity poles tilted over towards roads in places due to foundation related damage from soil failure, notably across River Road near Waiau township. The poles themselves were not typically damaged, with 85-90% of poles simply being stood back up, however drooping conductors can prove hazardous to people, machinery and livestock. There were some reported cases of livestock dying following electrocution following the earthquake. Around 95% of customers district-wide were reconnected by the end of the week (18 November 2016).

While the Waiau township electricity network was restored within two days, rural areas were considered a low priority to repair due to the lower population numbers serviced. It was estimated to take a long time to repair rural feeders, so the decision was made to delay this in favour of focusing on easier repairs to lines servicing towns. This is further justified by the fact that there was little demand for power at the time in rural Waiau. Irrigation is identified as a seasonally elevated power draw in rural areas. A new digital tool was developed by the end of the second day to track which buildings had been visited and relivened, essential for maintaining efficiency. Good coordination with the HDC building inspection team was critical, as relivening lines to damaged buildings is potentially dangerous.

A non-functioning electrical grid was generally not an issue for the restoration of other services in Waiau as diesel generators and fuel supplied from farms were readily available. Downed powerlines were an obstacle to restoring certain roads, however. Some farmers and other business operators quickly acquired mobile generators if they did not own them already. For example, Brenda's Café, a township establishment, received a generator on loan from the HDC as access to food and drink was deemed important for response and recovery personnel. Generators are the preferred back-up alternative, particularly on farms. 'Renewables' such as solar have not had much uptake as a secondary power source in Waiau. The cost is deemed to be inhibiting the uptake of solar equipment – both in initial cost and the long-term cost-benefit relationship.

4.2.7 LOS for Roads and Water Over Time

As part of the examination of interdependencies in Waiau, roads and water have been investigated further in a level of service (LOS) analysis. This involves looking at changes and trends in level of service over time in Waiau for these specific lifeline services. Roads and water were chosen for the high value of data retrieved about them from interviews and accessibility of shapefiles for integration as maps (Figure 4.4). The Canterbury CDEM group situational reports for the 2016 Kaikōura earthquake also provided a high resolution of level of service data over time. Details for each LOS map are given in Table 2, with daily data across several lifeline services offered in Appendix I**.** Trends over time are plotted in Figures 4.5 and 4.6. A major intent of this LOS analysis was to try to observe known interdependencies arising out of this pair of lifeline services, notably that of road access restoration allowing for the restoration of water schemes, and identify previously unknown ones.

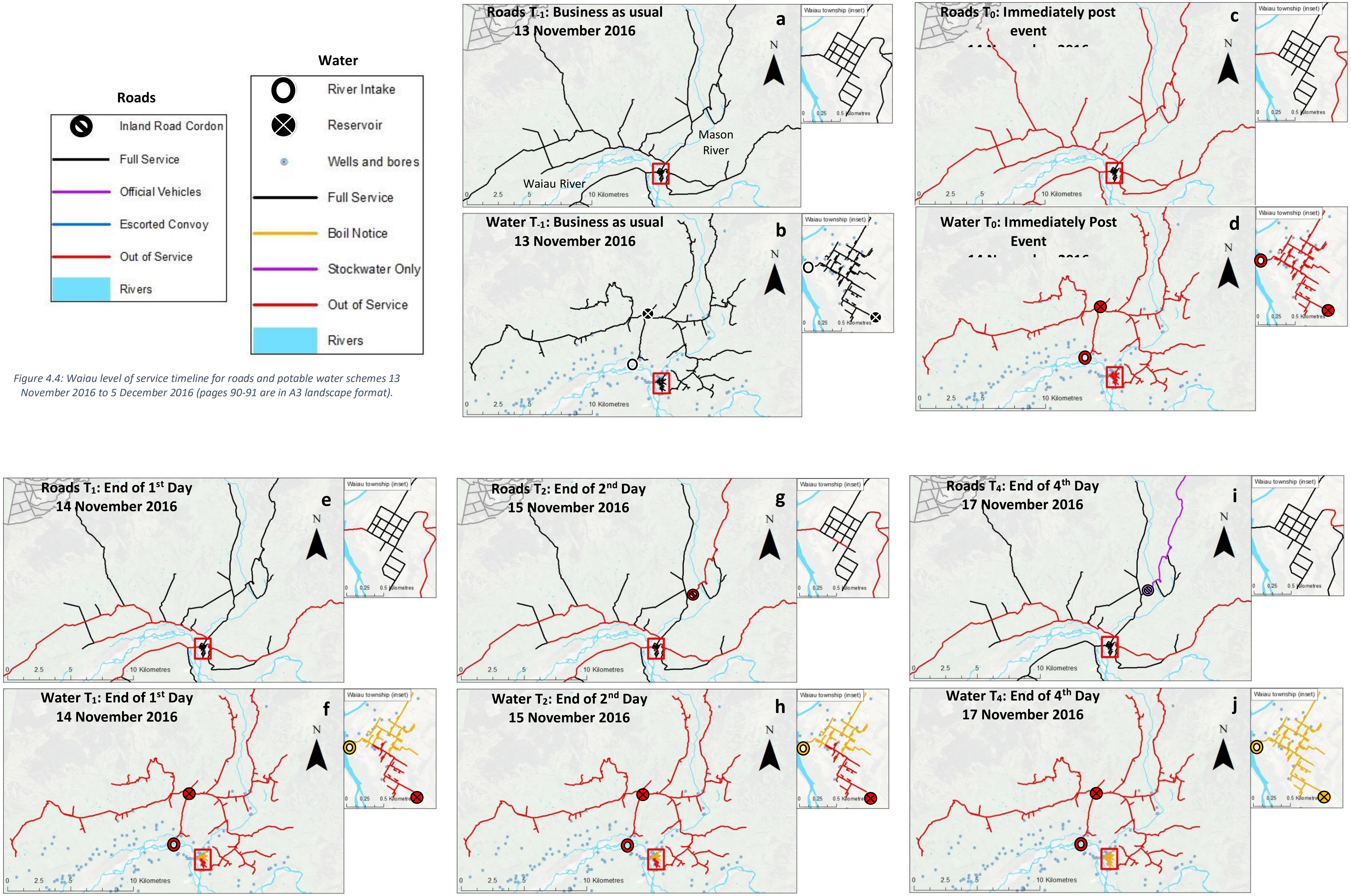
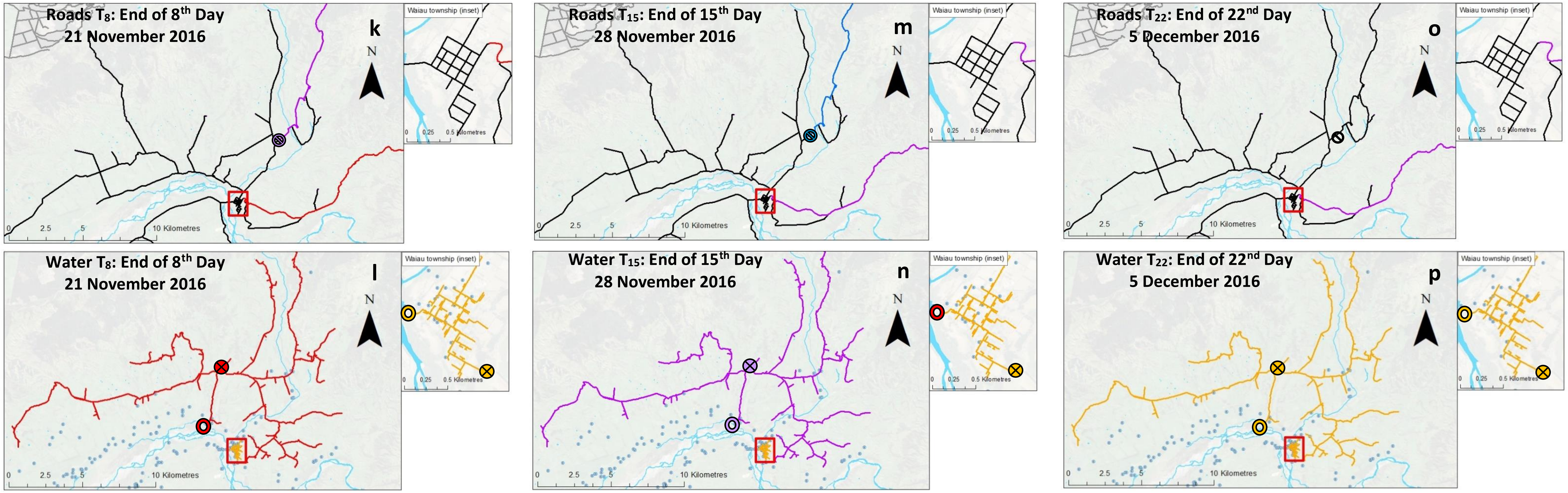


Figure 4.4: Waiau level of service timeline for roads and potable water schemes 13 November 2016 to 5 December 2016 (pages 90-91 are in A3 landscape format).



Roads T8: End of 8th Day
21 November 2016
k
N
Waiau township (inset)
0 2.5 5 10 Kilometres
0 0.25 0.5 Kilometres
Roads T15: End of 15th Day
28 November 2016
m
N
Waiau township (inset)
0 2.5 5 10 Kilometres
0 0.25 0.5 Kilometres
Roads T22: End of 22nd Day
5 December 2016
o
N
Waiau township (inset)
0 2.5 5 10 Kilometres
0 0.25 0.5 Kilometres
Water T8: End of 8th Day
21 November 2016
l
N
Waiau township (inset)
0 2.5 5 10 Kilometres
0 0.25 0.5 Kilometres
Water T15: End of 15th Day
28 November 2016
n
N
Waiau township (inset)
0 2.5 5 10 Kilometres
0 0.25 0.5 Kilometres
Water T22: End of 22nd Day
5 December 2016
p
N
Waiau township (inset)
0 2.5 5 10 Kilometres
0 0.25 0.5 Kilometres

Table 4.1: Narration of Level of Service maps (Figure 4.4)

Time	Roads	Water
T_{-1} Business as usual (13 November 2016, Figure 4.4 a, b)	- Business as usual - Main roads leaving township are i. Rotherham Road (Route 70 south to Rotherham, Culverden, SH7) ii. River Road (West to Leslie Hills Road) iii. Leslie Hills Road (West to SH7) iv. Leader Road (East to Cheviot, SH1) v. Inland Road (Route 70 north to Kaikōura) vi. Lyndon Road	Two independent water schemes servicing Waiau: i. Waiau township supply ii. Waiau rural supply
T_0 Immediately after earthquake (14 November 2016, Figure 4.4 c, d)	- Most bridges intact but shifted off abutments – pedestrian access possible - Leader Road blocked by slips, road damage - River Road blocked by road damage, riverside subsidence, downed powerlines - Rotherham Road blocked by road damage, downed powerlines	- Both schemes shut down with extensive damage - Town supply tank farm tanks twisted off couplings so no storage capacity, upslope piping between water network and tanks damaged anyway so no exchange with town or intake would be possible
T_1 End of the first day (14 November 2016, Figure 4.4 e, f)	- HDC (District) monitoring and investigating roads - Inland Road (Route 70) cleared and reopened	- Both water supplies inspected - Repair crews dispatched, restoring and reconnecting the town water supply systematically. Key issue is the Lyndon Road water main - No service in the rural supply - Boil notice in place district-wide
T_2 End of the second day (15 November 2016, Figure 4.4 g, h)	- NZ Transport Agency becomes responsible for Inland Route (Route 70), closed again - Township roads being dug up and blocked by vehicles repairing water mains, including along Lyndon Street	- Electronic monitoring of water flow not available due to continued power outage - Partial water service for Waiau township as water mains are repaired, township water chlorinated

T_4 End of the fourth day (17 November 2016, Figure 4.4 i, j)	- Waiau bridge usable in both directions with assistance of stop/go sign (light vehicles only, no towing) - Culverden-Waiau portion of Route 70 reopens - Essential 4WD vehicles now able to access remainder of Route 70 with new segments of track converting the route into the Kaikōura Emergency Access Route (KEAR), still closed to public, army cordon in place - Leader Road remains closed - 66% of bridges in district assessed	- Residents and businesses advised to conserve water districtwide - Water supply network is restored in Waiau township - Water storage capacity improved at the tank farm - Boil notice still in place (lifted in most other townships) - Waiau rural supply is the only water scheme in the district not yet restored to working order
T_8 End of eighth day (21 November 2016, Figure 4.4 k, l)	- All bridges open, some with restrictions - Leslie Hills Road cleared - Route 70/KEAR open to military and essential vehicles only. Some locals are bypassing the cordon via temporary road on private property, interesting adaptation to a disruption in service that potentially impacts negatively on other operations and own safety - 50 kmph speed limit across district roads	- Greater focus on restoring the Waiau rural scheme (river intake to reservoir, marked on map) - Pods of potable water distributed to rural residents - Reports of gastro bug sickness in Waiau (likely contaminated water, boil notice still in place) - Waiau town water storage volume fully restored, but continues to run at reduced capacity
T_{15} End of the fifteenth day (28 November 2016, Figure 4.4 m, n)	- Road and bridge status map made available online - Leader Road open to contractor and emergency vehicles, Leader river valley considered unsafe due to water levels behind landslide dam approaching limit - Conway River landslide dam burst, threatening the movement of vehicles on Route 70 - All 258 bridges in district have been inspected - Route 70/KEAR closed intermittently due to weather, exchange of control from military back to NZTA intended in coming days.	- A temporary intake in a nearby stream is installed to feed reservoir - New high-pressure pipe is rushed through production and installed in connection between river intake and reservoir - Rural scheme water not yet safe for people to drink but circulated for use in watering stock - 230000 L of stock water and potable water delivered per day to properties along Route 70/KEAR

T_{22} End of the twenty-second day (5 December 2016, Figure 4.4 o, p)	- NZTA managing Route 70/KEAR again, now allowing limited public access pending registration of road users. Alternating dates for light and heavy vehicles. Some dates cancelled due to poor weather. - Communications broke down between road contractors and residents regarding opportunities for driving the route	- Most Waiau rural water scheme users have supply restored by this time - Boil water notice still in place for drinking water on both the rural scheme and town.

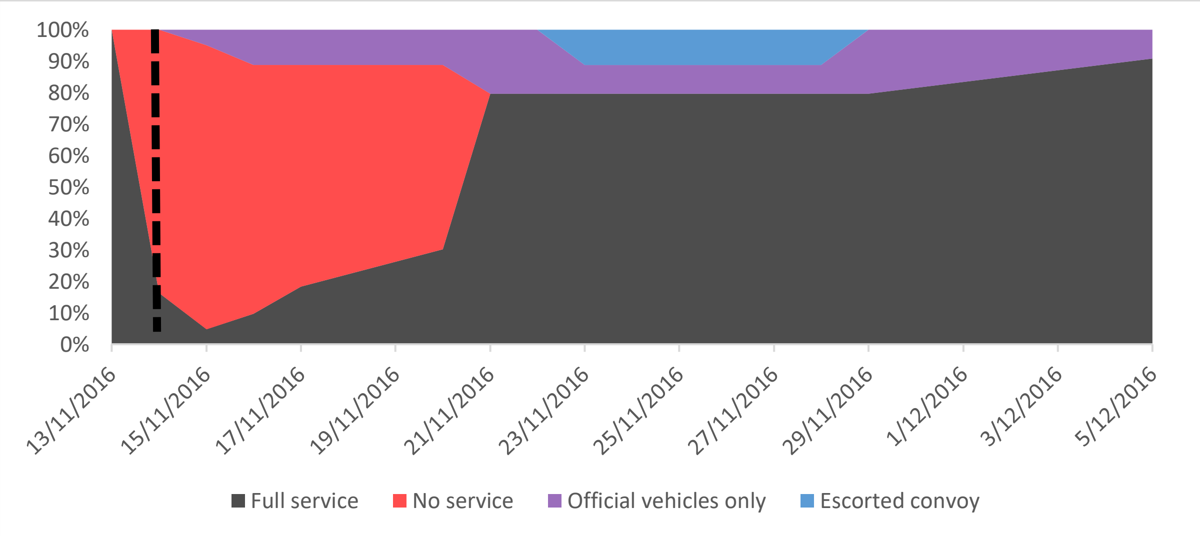


Figure 4.5: Average roading level of service in the Waiau study area from 14th November 2016 until 5th December 2016. Marker line denotes time of the 2016 Kaikōura earthquake.

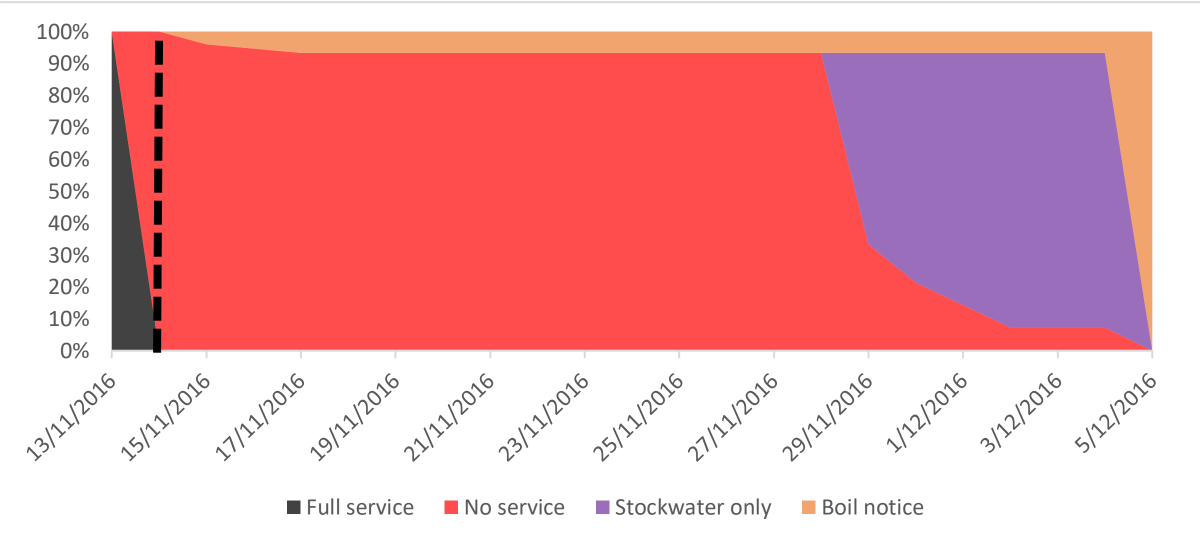


Figure 4.6: Average reticulated water supply level of service in the Waiau study area from 14th November 2016 until 5th December 2016. Marker line denotes time of the 2016 Kaikōura earthquake.

4.2.7.1 LOS Discussion

Immediately following the earthquake, all roads in Waiau outside the township were damaged or blocked in some way. By the end of the first day (14 November 2016), many side roads were cleared by locals and the Inland Road was reopened by HDC. 'No service' LOS for roads increased on the day after the earthquake (15 November 2016) as the Inland Route was closed again by NZTA. NZTA later reopens this road, but for approved vehicles only. From 17 November the Inland Road cordon is operated by the military, who from the 23 November escort vehicles by convoy to Kaikōura. Control of the route returns to NZTA from the 5 December and is reopened to approved applicants. As fallen powerlines are cleared from River Road and Leslie Hills Road, road LOS is restored to 'full service'. Roads do not reach 100% full service in these graphs as Leader Road continues under 'official vehicles only' status beyond the end date of this analysis (5 December 2016). A gap in road LOS information was when exactly Leader Road returned to 'full service'.

Both water schemes were fully shut down due to damage. A large proportion of rural residents regained service from the rural water scheme once the intake-to-reservoir section of piping was restored, and the vast majority of rural customers regained service gradually by 5 December. The town supply was restored within four days (17 November 2016). Water does not reach 'full service' again in these graphs as the boil notice continued for Waiau's water schemes past the end date of the analysis. Waiau rural water supply continues to be under a permanent boil notice as of February 2019.

Clearing River Road and Leslie Hills Road allowed heavy vehicles to access the intake-to-reservoir pipe section of the rural water scheme for repairs, which is why rural water LOS appears to lag behind the LOS for River Road. There is an eight day difference between the end of no service for River Road and the beginning of 'stockwater only' LOS for the rural water scheme. This is consistent with the time taken to begin digging up the intake-reservoir pipe section, manufacture and delivery of new piping, and restoration of the intake-reservoir pipe section described in Section 4.1.2.2. From this point onwards, the remainder of the rural water scheme is gradually brought back online to a 'stockwater only' standard. Conversely, in the township scheme road service is lost along Lyndon Street as water mains are being repaired. Here, the road LOS is instead dependent on the state of the water LOS.

It is important to note that in Figures 4.5 and 4.6 transitions between days can be misleading, as each 'day' plotted in the charts is informed by the LOS at the end of the day in reality. This obscures changes that occur throughout the day, as only LOS at the end of the day is shown. Conversely, this also results in steep slopes where in fact changes were effectively instantaneous and not gradual, such as the transition from 13 November 2016 into the 15 November 2016 in both charts which conceals not only the immediate LOS post-earthquake, but also the rate at which loss of service occurred. For day-to-day changes in LOS this is acceptable.

4.2.8 Lifeline Sector Interdependence Matrices

Interdependence between lifeline services is observed with regularity when reviewing lifeline performance in Waiau. It is important to compare a business-as-usual state with an emergency state in order to build an understanding of emergent relationships between lifelines, which can change radically. We can then use this to anticipate change and pre-emptively forecast the most relied on lifelines during emergency conditions, thus improving resilience.

The following service interdependence matrices (Table 4.3) are adapted from an example in New Zealand Lifelines Council (2017) to match Waiau's specific circumstances. Each table is accompanied by a justification for their results. These results are an estimation based on literature and research interviews.

1(Table 4.2) (a) 'Business as usual' and (b)Post-event lifeline sector interdependence matrices for Waiau
3 = Required for service to function
2 = Important for function or required in maintenance/other non-operative performance
1 = Minimal or nil requirement

a

Degree to what this > Is dependent on this v	Electricity	Roads	Fuel	Wired Telecomms.	Water Supply	Stormwater Drainage	Aviation	Broadcast Telecomms.	Total
Electricity		1	3	3	3	1	1	3	15
Broadcast Telecomms.	2	2	2	2	2	2	3		15
Roads	2		3	2	2	2	1	2	14
Fuel	2	2		2	2	2	1	2	13
Wired Telecomms.	2	1	2		2	1	1	2	11
Stormwater and Drainage	1	2	1	1	2		1	1	9
Water Supply	1	1	1	1		1	1	1	7
Aviation	1	1	1	1	1	1		1	7
Total	11	10	13	12	14	10	9	12	91

b

Degree to what this > Is dependent on this v	Electricity	Roads	Fuel	Wired Telecomms.	Water Supply	Stormwater Drainage	Aviation	Broadcast Telecomms.	Total
Broadcast Telecomms.	3	3	3	3	3	3	3		21
Roads	3		3	3	3	3	1	3	19
Fuel	3	3		3	3	3	1	3	19
Electricity		1	3	3	3	1	1	3	15
Aviation	2	2	1	2	2	2		2	13
Wired Telecomms.	2	1	2		2	1	1	2	11
Stormwater and Drainage	1	2	1	1	2		1	1	9
Water Supply	1	1	1	1		1	1	1	7
Total	15	13	14	16	18	14	9	15	114

The following are simplified relationships for business-as-usual sector interdependence for before the earthquake (Table 4.3a):

- The electrical grid relies on roads and fuel to support day to day maintenance, and a mix of wired and broadcasted telecommunications for general operation.

- Roading requires the effective drainage of stormwater to keep drivable. Fuel and broadcasted telecommunications are necessary for maintenance.

- Transport of fuel relies heavily on roads. The operation of commercial pumps and other related equipment is only possible with electricity, and there were few backup generators for fuel stations in Waiau. Telecommunications are important for domestic purchasing of fuel and other day to day operations.

- Wired telecommunications include both buried and pole mounted cables. While copper-based wired telecommunication methods do not require the electrical grid to function, fibre and most receiving and transmitting devices do. Roads, fuel and broadcast telecommunications are needed in maintenance.

- The reticulated water supplies of Waiau need electricity to operate pumps. Telecommunications are critical for remote control and telemetry collection. Roads, fuel and broadcasted telecommunications are needed in maintenance.

- Waiau stormwater drainage only requires roads, fuel and broadcasted telecommunications during clearing and other rare maintenance.

- Broadcasted telecommunications run on electricity, often with battery cells for a backup power source. Roads, fuel and further broadcasted telecommunications are needed in the maintenance of transmitter towers.

- General operation of aircraft is heavily aided by broadcasted telecommunications.

In the New Zealand Lifeline Council's (2017) lifeline sector interdependency matrix, fuel becomes the most depended on service post-event. This is followed by roads, and then telecommunications. For Waiau specifically, we see broadcast telecommunications rise in criticality over roads and fuel, the latter of which now have the same score, reflecting a combination of different weighting based on observed needs and the reclassification of sectors in this adapted version.

Broadcasted telecommunications were needed in every sector for effective coordination in recovery. Roads and fuel were required to relocate and operate recovery equipment in all sectors considered. Fuel was also used in numerous electricity generators where power was yet to be restored. Electricity dependence does not appear to change, although the use of generators alleviates pressure on electricity-dependent sectors. There are no further changes in interdependence shown in these matrices. My findings generally support those of the NZ Lifelines Council Study (2017).

The importance of aviation is moderately raised post event, as in Waiau there was some initial scouting by infrastructure managers to evaluate the extent of infrastructure damage. Usage of helicopters was otherwise limited to uncommon cargo transport such as the airlift of fibreoptic cables. This is in contrast to Kaikōura where helicopters were used frequently for reconnaissance, as well as the transport of emergency response personnel and tourists.

An argument could be made that services which rely on a fuel of sorts will inherit the dependencies of that fuel, however we assume here that the services are sufficiently disconnected, either by geography or through sufficient local fuel storage, so we may faithfully depict immediate needs.

It should be noted that the values displayed here only represent surface concepts of interdependence and do little to describe the actual change in units of service needed in each sector. For instance, the repair of critical infrastructure significantly increased the usage of roads by each sector. However, this matrix can only tell us that road access grew in importance, not actual road usage in terms of travel times, traffic volumes, or tonnage moved.

4.2.9 Special facilities

Waiau possesses several socially important and historic buildings that were damaged in the earthquake (Figure 4.7).

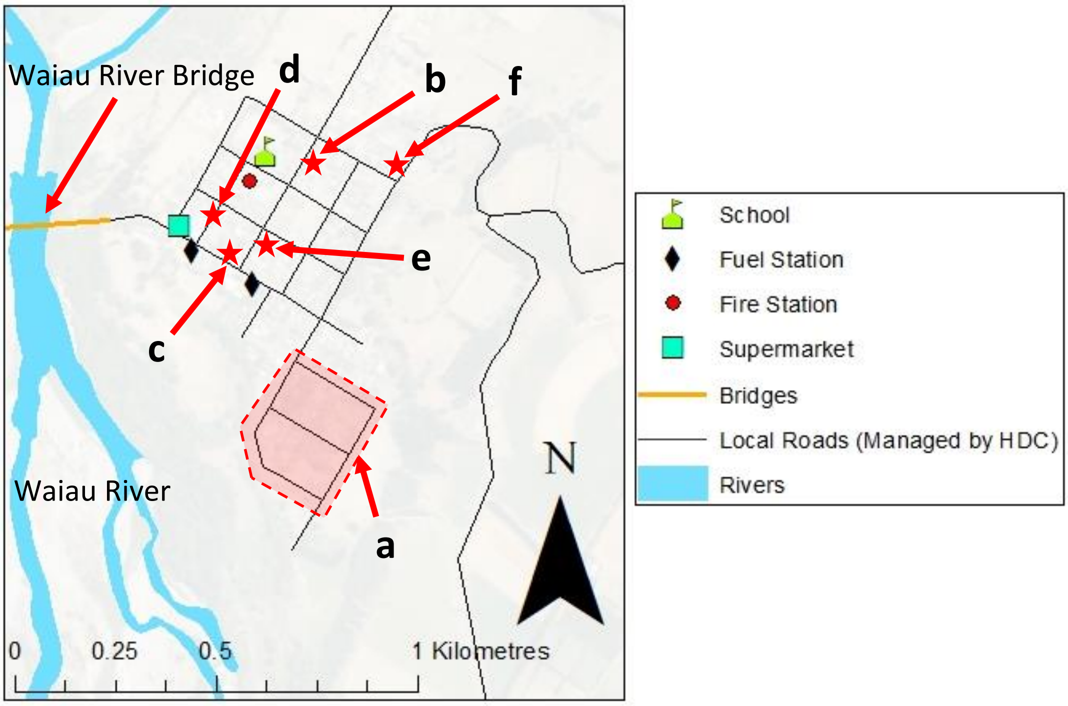


Figure 4.7: Annotated Waiau township. (a) High damage residential zone, (b) Waiau Recovery Village site, (c) Historic 'Waiau Lodge Hotel' and pub, (d) Town Hall, (e) Cobb Cottage Museum, (f) All Saints Church.

The 107-year-old Waiau Lodge Hotel building and accompanying pub (Figure 4.7, c; Figure 4.8) functioned as an important meeting place for locals before the earthquake. It received a red placard following rapid assessment by HDC. This building was not replaced with an alternative, the Waiau Tavern, for six months. This restricted public gathering to more formal venues such as the school and later the town hall (Figure 4.7, d). Once deemed structurally safe, the town hall was used as a recovery hub instead (see Section 4.2.4 for more details).

Figure 4.8: Waiau Lodge Hotel, Waiau (D Dizhur and M Giaretton, 2016).

The Cobb Cottage was built in the 1860s, and currently operates as a museum housing rural memorabilia (Figure 4.7, e; Figure 4.9). The chimney collapsed with two walls partially collapsing, however the structure is generally intact (Radio NZ, 2018). Exhibitions are now held in a wooden former Presbyterian church on the grounds.

Figure 4.9: Cobb Cottage, Waiau (D Dizhur and M Giaretton, 2016).

Figure 4.7, f (Figure 4.10) refers to the All Saints joint Anglican-Presbyterian church, which was also given a red placard for damage suffered in the earthquake. While repairs are possible, it would cost an estimated $1.2 million with no insurance. Until this spiritual centre of Waiau township is restored, church services operate out of the town hall.

The two fuel stations in Waiau were unusable until electricity was restored to Waiau. This is due to a common lack of investment in backup generators prior to the earthquake. There was an early reliance on farm stockpiles of fuel as a result, which needed to be carefully rationed.

Figure 4.10: All Saints Church, Waiau (D Dizhur and M Giaretton, 2016).

Milking cows in rotating sheds is a common method for dairy farmers in New Zealand, however several of these specialised sheds were thrown off their bases or rendered unusable by lack of electricity. Farmers shared milking facilities and diesel generators to make up for these. Road access was restored soon enough that no milk needed to be dumped.

4.2.10 Residential Housing

Many houses in the Hurunui district are old farmhouses which do not meet modern building codes. Waiau township in particular is a very low socioeconomic area so new developments are uncommon.

20% of placarded buildings in the Waiau area were assigned a red placard following the rapid assessment used in Hurunui (Section 3.2.6.1). These houses are deemed uninhabitable due to damage, displacing residents. Within the township and in the wider rural area, there were 22 red and 15 yellow placards. Examples of damage include collapsed chimneys, buckled walls and collapsed ceilings. One resident of a red placarded dwelling was found by inspectors carrying a hatchet out of fear of further collapse and burial.

The township needed more housing assistance than farm residences – likely a combination of damage, money available for repairs and skills applicable in a recovery context. There were also fewer alternative accommodation options available in the township, increasing urgency. In contrast, the inhabitants of many farming dwellings had sheds or other buildings on their property that they could move into, following approval by building inspectors (Section 3.3.6.1) . Most of the residential damage in Waiau township was confined to the area delineated in Figure 4.7 (a). Residents' perceptions of house damage were diverse: some over-estimated structural damage whereas others believed their houses were completely safe despite "falling over in places". General sentiment appeared to welcome professional guidance when houses were deemed safe to occupy as this assuaged fear, yet there was considerable resistance from residents when inspectors concluded houses were unfit for occupation. This likely stems from denial from fear of displacement and the economic impact. In terms of residential building damage, Waiau was reportedly the least resilient town in Hurunui District.

Insurance cover in the town area was typically very low to match local house prices of $150,000-200,000. However, few alternative houses were available to buy due to damage and to rebuild a new home from scratch would cost far more than what these insurance pay-outs offered. There was significant concern for people choosing to live in damaged homes and spending the insurance money on non-essential commodities and debt. A social recovery team was established by HDC to help educate people on budgeting, insurance and the process of rebuilding. Temporary accommodation was difficult to find, as rentals and motels had been taken up by non-local contractors and workmen in the recovery phase. To help with this, HDC bought four prefabricated houses from the Minister for Housing and Development at $25,000 each, with payments deferred until the post-recovery phase. These houses were originally used in a 2011 Christchurch earthquake recovery village. Land for the Waiau recovery village was purchased in the township from church property trustees at market rate, providing a central location for easy accessibility (Figure 4.7, b; Figure 4.11). It took one month to prepare the village and one month building it, with many locals providing labour for free or at a reduced rate.

Figure 4.11: Waiau Recovery Village, Waiau (D McKibbin, 2018).

4.2.10.1 Use of Recovery Village

Despite the attractive concept of a recovery village, uptake was very slow. Two of the houses were left empty for the first six months, and only recently have they all been filled. It is believed that this is due to the late availability of the buildings, as by the time it was opened in July 2017 many displaced people had already found alternative accommodation. These included moving in with friends and relatives, or in some cases establishing themselves in their own garages and sheds. A detracting factor of the recovery village is that its homes were offered at market rent, which displaced people may not have been able to afford alongside paying for reconstruction and supplies for their real home. The village is likely to continue until mid 2019 or as needed.

4.3 Other Emergency Management and Population Considerations

4.3.1 Lifeline Utility Management

Perception of acceptable risk is identified by the UNISDR (2017) as changing based on social, economic, technical and environmental conditions. Political and cultural conditions are also strong drivers of acceptable risk (UNISDR, 2017). The way that lifeline networks are managed in emergency situations are sometimes criticised by the public. The Inland Road is a good example of residents who are happy to accept risks on an individual basis. These decisions are weighed personally, where they only really need to account for themselves. This is very different from the more political perspective of managers, who need to consider the lives, wellbeing and assets of many. Blocking access to the Inland Road was the easiest way to minimise people getting trapped or risk of fatalities in the area.

Adequate consideration of acceptable risk and expert knowledge was reportedly not always employed in Waiau. Residents quickly became frustrated when told they could not use the Inland Road, despite dangers communicated by officials. Landslide risk was not readily observable as it was concentrated much further along the Inland Road, perhaps leading the public to underestimate danger and overestimate acceptable risk. In contrast, landslide and slumping damage to more accessible, visible roads such as Leader Road appeared to spur greater caution. Diminishing concern for earthquake hazards over time was also apparent, with some people reportedly becoming complacent. It has gotten to the point where there are cases of those still rebuilding their homes or developing land actively trying to evade council regulations in favour of saving money. Some interviewees suggest that these are not problems restricted to Waiau, but are characteristic of public perception of disaster risk as a whole.

4.3.2 Volunteer Civil Defence

Volunteer Civil Defence teams in Hurunui are split into nine geographical sectors, each corresponding to major communities such as Mt Lyford, Hanmer Springs, Culverden and Amberley. Due to limited resources and different needs, the teams are not standardised and are given the opportunity to decide for themselves what effort to contribute. This freedom stems from a 'you get what you put in' practical ethic, intended to build resilience only as justified by the community. Understandably attendance to training sessions was varied, with an average of two to three volunteers per geographical sector, of whom many were also volunteer fire fighters. Pre-earthquake, Waiau meetings were organised however no volunteers would consistently attend. This may have resulted in a somewhat undertrained, underprepared and overwhelmed volunteer team.

A welfare team is supposed to be attached to each Hurunui sector team, operating out of sector posts, however there was no formal welfare team in place at the time of the earthquake. This severely limited the scope within which the volunteer teams could function.

Waiau School was used as a welfare post for the first week and a half before being transferred to the Town Hall, where it was transitioned into a recovery hub instead of a traditional 'welfare centre'. This choice was an adaptation informed by local needs. Two years on from the earthquake, Waiau has a team of eight civil defence volunteers, training monthly at the time interviews were conducted.

4.3.3 Transient populations

There was a very small transient population in Waiau at the time of the earthquake. The township acts as more as a rest stop than a tourist destination, especially for those going to or returning from Lyford Village and Kaikōura via the Inland Road (Figure 4.2, f), or Hanmer Springs using nearby SH7. As the earthquake occurred near midnight, the number of tourists travelling on the roads through Waiau was low. While seasonal itinerant labourers do work in Hurunui, such work and accommodation is mainly sited outside Waiau. For these reasons, transient populations were not a significant consideration during response and recovery in Waiau. Temporary infrastructure workers and tradesmen arriving from out of town increase demand for accommodation. As Waiau is located both at the end of the Inland Road and close to the alternative Christchurch-Picton route, thoroughfare traffic may have increased demand for accommodation further.

4.4 Summary

Chapter 4 approached the research questions in a more detailed manner, investigating a single town with greater depth than the four towns in chapter 3. Waiau was selected for its location close to the epicentre of the earthquake, vital routes used in the recovery from the 2016 Kaikōura earthquake and large amount of information gathered about it in interviews.

4.4.1 Roads

- Waiau is located at an intersection of important routes to Kaikōura, Christchurch and Hanmer Springs.
- Roads in Waiau experienced hazards similar to roads elsewhere in North Canterbury, Kaikōura and Marlborough. They were blocked by landslides, power poles and electrical conductors, and suffered damage from surface rupture and lateral spreading. Bridges were commonly shaken off their abutments.
- Locals helped to clear roads to give access to their homes.
- Inland Road adopted as main route into Kaikōura in response to the closure of SH1.
- Change in management of Inland Road from HDC to NZTA caused issues regarding residents' access to homes and farms.
- Unofficial detour was developed by locals to circumvent the Inland Road cordon.

4.4.2 Three waters

- Waiau was supported by two potable water schemes: Waiau Rural and Waiau Township.
- Township scheme was largely able to operate while repairs were carried out along the main road thanks to iterative restoration process and a mobile chlorination plant.
- Town supply tank farm's stored water rendered useless as shaking twisted tanks off couplings causing leaks.

- Branching rural water schemes encounter unique challenges which circulatory urban ones avoid.
- Key failure of the Waiau rural water scheme occurred along the intake-reservoir section, which was the only business as usual intake in the scheme.
- Replacement piping for the intake-reservoir section was rushed through production in response to support the recovery effort.
- Permanent boil notice in place for the rural water scheme.
- Stormwater drainage was not a significant issue for Waiau.
- Waiau residents are on sceptic tanks rather than any centralised system, which boosts resilience as failures were limited to individual tanks.

4.4.3 Telecommunications

- Waiau lost all mobile phone coverage despite having a relatively new mobile phone tower.
- Waiau landline exchange was not damaged, however cables connecting to it were.
- There was a heavy reliance on VHF radio to make up for loss in service.

4.4.4 Electrical networks

- Kaikōura and Waiau distribution networks are fed from the same GXP in Culverden, which failed in the earthquake.
- Pole performance similar to rest of North Canterbury, Kaikōura and Marlborough. Poles tilted, conductors stretched and tangled with trees or other objects.
- Conductors drooping or lying on the ground are a significant hazard to machinery, people and livestock.
- Waiau township restored within two days (16 November 2016).
- 95% of customers restored by the end of the week (18 November 2016).
- Electricity supply generally not an issue in restoring other critical infrastructure and lifeline services in Waiau as diesel generators were in common use.

4.4.5 LOS analysis

- Waiau rural water supply restoration dependent on road access for heavy machinery and replacement pipe delivery.
- Waiau township road LOS regressed during repairs to the township water supply.

- Pre-earthquake LOS not restored for the rural water supply (permanent boil notice).
- Interdependencies
- Water schemes required road access before repairs could begin.
- Fallen electrical conductors along River Road and Leslie Hills Road needed to be restored before the road beneath could be used.
- Bridges carrying other infrastructure types such as landline telecommunication cables identified as pinch points for multiple networks.
- Electricity scored as the most depended on of lifeline services in the business-as-usual interdependency matrix.
- Broadcast telecommunications scored as the most depended on of lifeline services in the emergency interdependency matrix.
- Very little use of aircraft in Waiau compared to the rest of North Canterbury, Kaikōura and Marlborough.

4.4.6 Special facilities

- Several landmark buildings were damaged in the earthquake.
- Schools played big part in disseminating information to families.
- No milk was dumped in Waiau thanks to quick restoration of roads.

4.4.7 Housing

- Dwellings in Waiau are typically old buildings, especially in the township where new developments are uncommon due to socioeconomic status.
- Insurance cover typically very low in the township to match income, however this resulted in greater hardship.
- Waiau Recovery Village was useful for people who used it, however it was set up too late to help relieve many displaced families who had already moved on.

4.4.8 Emergency Management

- Levels of acceptable risk were different for Waiau residents and emergency personnel, leading to conflict and distrust.
- Visibility of earthquake impacts and hazards influences perception of risk for locals.
- Diminishing concern for hazards over time was identified.

- Waiau’s volunteer civil defence team has greater dedication following the earthquake.
- Transient populations put pressure on temporary accommodation options in Waiau.
- Waiau’s strategic location on important roads and other critical infrastructure networks has earned it extra support in earthquake recovery.

Chapter 5: Conclusions

5.1 Overview

This thesis investigated impacts to critical infrastructure and lifeline services from the 2016 Kaikōura earthquake and how these affected people living in small rural towns. Adaptations to the resulting disruption of service were also identified and evaluated. This chapter will summarise key findings regarding impacts to infrastructure, lifeline service interdependencies, adaptations and limitations to this thesis. Opportunities for future research are also identified.

5.2 Summary of findings

5.2.1 Key Impacts and Disruptions

Understanding impacts to critical infrastructure networks and the resultant disruptions to lifeline service is a priority under the Sendai Framework for Disaster Risk Reduction. Combining understandings of hazards, vulnerability, exposure and resilience allows researchers to determine disaster risk as proposed in the United Nations International Strategy for Disaster Reduction's (UNISDR) disaster risk formula (Section 1.2.1). The following are some of the key impacts and disruptions identified in this investigation.

- Roads were commonly blocked by landslides in gorge and coastal areas, often just outside small rural towns or along important routes such as SH1, physically isolating them from larger population centres that they rely on for goods and services.
- Bridge spans were left largely intact, however many of these had been shaken off their abutments – damaging infrastructure carried by the bridge. As infrastructure networks in rural areas tend to have few redundancies, failure at these pinch points can shut down large swathes of network.
- Damage from shaking and ground deformation to three waters schemes was most apparent at fixtures between pipes and apparatuses such as water tanks or junctions. Older tanks and piping were most vulnerable to damage.
- The community operated water schemes of Ward required significant assistance from the Marlborough District Council (MDC), suggesting that both scheme stakeholders and authorities need to come together to discuss expectations and responsibilities.

- Electrical networks were widely impaired by poles tilted by shaking and ground deformation, stretching and breaking conductors. Conductors were also broken by falling trees and landslides. Critical facilities such as substations suffered damage from shaking.
- Telecommunication capabilities were significantly reduced by loss of power to transmitting towers and landline exchanges.
- Many buildings survived the 2016 Kaikōura earthquakes in Seddon and Ward due to earthquake strengthening prompted by the 2013 Seddon and Lake Grassmere earthquakes.
- In the 2013 Seddon earthquake Seddon wastewater pipes running east-west were damaged, while pipes running north-south were relatively unharmed. No such pattern was observed with the 2016 Kaikōura earthquake.

5.2.2 Key Interdependencies

An important part of this study was to identify the interaction of lifeline services as interdependencies. Interacting lifelines produce complex relationships where the failure of one can have cascading impacts on others. In rural settings, it can take some time to restore infrastructure so prioritisation is a must.

- Under business as usual conditions in Waiau, the lifeline service most depended on by other lifelines is electricity, followed by broadcasted telecommunications and roads. In emergency conditions post 2016 Kaikōura earthquake, broadcasted telecommunications becomes the most depended on followed by roads and fuel.
- Broadcast telecommunications are required for the coordination and monitoring of every sector in recovery.
- Roads facilitate not only the transport of supplies, but of infrastructure repair crews as well. Heavy equipment requires road access to be restored before it can enter a given area and repair infrastructure.
- Fallen conductors block roads. Until these are cleared, it can be difficult for repair crews to fix other forms of infrastructure. This appears to have contributed to the delay in restoring the Waiau rural water supply, which required excavators.

- While electricity services are required to run many other kinds of services, the majority of critical infrastructure nodes are equipped with some form of backup power source.
- Reliance on aviation is considerably lower in Hurunui than in Kaikōura and Marlborough.

5.2.3 Key Adaptations

The adaptations observed in this investigation are particularly novel. Some may have applications for other small rural towns facing similar circumstances after an earthquake. Adaptations reactively improve resilience as difficulties are encountered, however by documenting them in past events emergency management can prepare to support similar actions in the future, or even incorporate aspects into emergency planning.

5.2.3.1 Transport

The Inland Road cordon's exclusivity created an artificial disruption of road service. This prevented people from getting to their homes and livestock. To avoid this, locals developed an unofficial detour over private land. This enabled the restoration of local access, however it was problematic as people were ignoring emergency management's warnings and potentially exposing themselves to danger, as well as using sections of road earmarked for infrastructure recovery vehicles and supply convoys.

Without water delivered by the Waiau rural water scheme, farmers began to encounter difficulty watering their stock. To alleviate this issue, they collectively removed fences near rivers and streams and allowed stock to drink from them. Allowing stock to drink from waterways is usually illegal however the Hurunui District Council (HDC) waived this rule to support the wellbeing of farmers and their businesses.

5.2.3.2 Electricity and Fuel

Loss of electricity can be devastating for other lifelines services, industry and the community at large. Rotating milk sheds in Waiau could not operate without power, for example. Diesel generators were the preferred electricity backup option for Waiau, as most farmers already owned or could quickly purchase them. Certain businesses and essential sites which could not source a generator were loaned one from HDC.

A significant drawback of using generators is that fuel must be stockpiled, and then replenished, over time. While fuel can be stockpiled easily on farms during business as normal this is not as easy for township residents, who have both less space and typically lower incomes. When roads are blocked, isolated communities will have additional difficulty sourcing supplementary fuel. Farmers shared their stockpiles of fuel while roads were blocked

5.2.3.3 Emergency Housing

Where people must vacate their homes due to building damage or access issues, suitable alternative accommodation must be found. For small rural towns, alternative options following a disaster are severely limited as:

- There are few undamaged local homes available on the market
- Hotels, motels and hostels are booked up by recovery personnel, tradesmen and other displaced locals
- Options in other towns demand long commutes or are impractical due to road closures and long detours
- Displaced people may have difficult financial situations between being put out of work, rebuilding their homes or a poor BAU financial situation

Emergency management and local government therefore can relieve significant socioeconomic pressure by providing temporary accommodation to displaced peoples. Lessons learned in the 2016 Kaikōura earthquake show however that sourcing and installing temporary accommodation is costly and takes a significant amount of time – eight months in the case of the Waiau Recovery Village (WRV). HDC housing inspectors allowed farmers with red placarded homes to stay on their property when sheds and other buildings were of a habitable standard, helping to reduce the strain on resources in the township and letting farmers continue to work with stock and repairs.

5.2.3.4 Social

Unreliable telecommunications and electricity exacerbate already difficult communication across rural areas. Focal points such as pubs provide a meeting space where people can discuss their experiences and challenges with others, as well as share skills and consolation, in a comfortable setting. The Waiau Lodge Hotel received a red placard, pushing such gatherings to the Waiau Town Hall. As this did not fulfil informal requirements, popular demand saw a return to a temporary pub erected on the Waiau Lodge Hotel property. In Ward, regular barbeques outside the Ward Town Hall filled this role. Even infrastructure managers attended, allowing them to assuage concerns and better understand local priorities. Sometimes these properties were host to multiple services at once, including emergency shower blocks, water distribution points and civil defence sector posts.

Immediate economic resilience of residents and physical resilience of dwellings are demonstrably tied to economic disparity. Farming families are typically resilient economically as well-planned businesses will be able to absorb some level of losses from disaster. It is important to note however that several successive disasters in a short period of time will prove challenging. Flexibility in allowing farmers to stay on their property is effective in that emergency resources are saved by not rehoming them, residents can continue to look after livestock and they can begin rebuilding on their own. In comparison, low incomes in townships tend to leave residents in old, less resilient dwellings which they cannot afford to update. Low incomes also result in low insurance payouts, reducing the options for lower socioeconomic classes to rebuild or relocate. Many people in this situation moved onto the properties of friends and family in tents or garages, highlighting the importance of strong social bonds in a community.

Small rural towns are often remote, which poses a challenge when residents need to access services such as healthcare or insurance. People living in lower socioeconomic conditions may need extra assistance. As it can be difficult for outsiders to earn the trust of close-knit rural towns, the DHB's Navigator system is efficient. A single person acts as a liaison between residents and services, passing information between them and giving advice on how to use services. Community navigators have demonstrated that they can build rapport with a community and deliver information that the DHB and emergency management can use for optimising their approaches.

5.2.4 Limitations

There were some challenges with acquiring geospatial data for maps. Time constraints and commercial sensitivities restricted the publication of some datasets, hence why they have not been made available in the figures of this thesis. Geographical datasets depicting rivers were surprisingly poor, with entire tributaries such as the Mason River being absent – requiring manual addition. Some datasets needed to be updated or replaced entirely with the publication of new research over the course of the thesis. Often, there was a lack of ideal data covering the small towns investigated purely because previous studies have focused on larger urban centres like Kaikōura town.

A major limitation with using interviews as a primary information source is that the human element complicates findings. Accuracy in collected data is restricted to the expertise, experience and views of the interviewee, which must then be reinterpreted by the researcher. In this thesis such issues were mitigated by seeking out experts and personnel who experienced the 2016 Kaikōura earthquake first hand. The utmost care has also been taken to not misrepresent the interviewees in writing.

The Canterbury earthquake sequence and 2013 Seddon/Lake Grassmere earthquakes affected the earthquake response of the small towns in this study. The 2016 Kaikōura earthquake was not an unfamiliar event for many people, which may have skewed our findings in favour of resilience in small rural towns. This is especially true for Seddon and Ward. Despite this, the ability for communities to learn from previous earthquakes is a valuable observation to investigate.

Another considerable difference between the towns in our study was that the November/December 2016 heavy rain events had little impact in Hurunui, despite escalating issues significantly for those in Marlborough. The rain reactivated landslides and threatened homes still damaged by the earthquake. Drainage and wastewater infrastructure was also put under strain, resulting in water contamination. Compounding hazards, while providing useful practical data, may potentially skew resilience data when some communities in a study are not affected by them. As the rural South Island is made up of highly variable terrain, circumstances are likely to arise where given towns in a study will be subject to an inconsistent distribution of compounding hazard types and intensities. Despite geographical differences, the similar size and demographics of the towns enabled useful comparisons to be made.

5.3 Opportunities for Future Research

- With the proliferation of mobile devices in the past decade, we are seeing the adoption of new emergency management systems with near-instant communication between administrative bodies and the public. Recent Information and Communication Technologies [ICTs] tested in New Zealand have included the Emergency Mobile Alert [EMA] system, where alerts can be broadcast directly to compatible devices during a crisis (MCDEM, 2017b). Person-to-person communication of real time issues following an event may be inhibited in a rural community, where problems such as distance and obstructions are not mitigated by population density (Gerald, 2016). The EMA system was put into practice during ex-tropical cyclone Gita in February 2018, where it was used to disseminate information detailing water management and safety concerns (Taranaki CDEM Group, 2018). The efficacy of these systems in events where telecommunication networks may be brought down temporarily is a possible avenue for future research.

- Many residents along the Inland Road live on lifestyle blocks, and so do not neatly fit into the traditional township-farmer dichotomy. This puts lifestyle block owners in a difficult situation, as they face challenges shared by both township and rural residents. This becomes an issue as rural support organisations tend to be focused more towards rural businesses, whereas organisations geared towards assisting township populations. Investigation into adequate support for different levels of rural living has been identified here as an avenue of further research.

- The Inland Road cordon detour across private property, along with moving stock through public land to access water, are examples of flexible transport solutions that are successful in rural contexts. They represent potential redundancies capable of relieving pressure on residents, emergency services and infrastructure repair crews where orthodox transport routes fail. Identifying novel flexible transport solutions now for the benefit of emergency management may prove effective in rural areas where traditional redundancies are uncommon.

- The four phases of psychosocial recovery noted throughout this thesis are applicable in many different disaster contexts. Small rural towns are not necessarily unique in their needs, however access to support services is more difficult. While economically more resilient than township residents, farmers could possibly benefit from better support availability in the long term as depression and monetary issues appear to become most apparent in the latter phases of recovery. More specialist research is needed into this as it is beyond the scope of this thesis and discipline as a whole.

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Appendix I

High resolution timelines of service

Date/Time	Roading	Water	Electricity	Comms.	Industry	Other
2016-11-14 0002	Bridges dropped from abutments Roads impassable from Culverden to Waiau Leader Road blocked by slips, road damage Inland Road blocked by slips, road damage River Road blocked by road damage, riverside subsidence and downed powerlines	Waiau rural and township schemes down Town supply tank farm tanks twisted off couplings so no storage capacity, upslope piping between water network and tanks damaged anyway so no exchange with town or intake would be possible	Inland Road and Waiau lost power Many poles down and power out Culverden substation damaged	18 cell sites with no power across Hurunui Waiau exchange isolated by cable breaks	Rotating dairy sheds fallen off rollers, most sheds are okay however	

	Rotherham road blocked by road damage and downed powerlines					
2016-11-14 1000				Generators deployed Spark engineers helicoptered in to install satellite phone link for the exchange (for 111 calls)		Welfare centres activated
2016-11-14 1156						HDC declares state of emergency
2016-11-14 1200		Water mains being checked in Waiau, electronic monitoring not yet			Farmers mostly using generators and neighbours’	

		available due to power outage Boil notice in place district wide			sheds to continue milking	
2016-11-14 1350						Helicopters able to refuel at Cheviot
2016-11-14 1745	Light vehicle access over Waiau bridge only, no towing					Rapid response team from Chch to feed Waiau residents
2016-11-14	Inland Road cleared and reopened by HDC	Both schemes inspected				
2016-11-15 0600				Spark phone outages	ECan issues advisory on stock drinking water access and milk disposal	60-70 people staying at Waiau school, half living in vehicles

2016-11-15 0900	Load test on Waiau bridge					
2016-11-15 1200						Local state of emergency declared for Canterbury Region
2016-11-15 1730	Emergency vehicles can access Waiau from the south		Distribution network power restored to Waiau	Vodafone coverage restored in all areas except Waiau, a femtocell linked to satellite to be deployed		60-70 evacuees now staying in cars at the Waiau Hall (welfare centre moved)
2016-11-15	Inland Road (Route 70) is taken under NZTA jurisdiction, is closed again	Partial water service restored for Waiau township scheme				
2016-11-16 0600		Water scheme users advised to save water			A wellbeing truck will visit farms to provide	School opened as usual

					information and support	
2016-11-16 1000	Culverden to Waiau road section open to all vehicles					
2016-11-16 1800	Track constructed along Inland Road, for essential vehicles only					
2016-11-17 0630		Water supply restored to Waiau township	Most of Waiau township reconnected, 262 homes in district still without power	Vodafone coverage fully restored in Waiau		Waiau Fuelstop still not operational
2016-11-17 1430	Army cordon now in place on KEAR/Inland Road					
2016-11-18 0630		2x gastro cases reported				Evaccuees no longer staying at Waiau Hall

2016-11-18 1500				Spark coverage fully restored in Waiau		
2016-11-19 1430		4x gastro cases reported				Waiau Rockgas has good fuel supplies
2016-11-20 1430			Power fully reconnected unless for safety reasons			
2016-11-20	Leslie Hills Road cleared					
2016-11-21 1430	Inland Road and Leader Road open to emergency and contractor vehicles	Additional gallery created in stream close to the rural scheme’s main reservoir to				

		provide stock water 6x gastro cases reported				
2016-11-22 1430	Some farmer access allowed on Inland Road/Kear route on case-by-case basis					
2016-11-23 1430	Communication issues over who and when Inland Road/KEAR access is allowed for					
2016-11-26 1100				Cellphone coverage issues between Waiau and Mt Lyford		
2016-11-28		230,000 L of stock water and potable				Waiau recovery hub operational

1200		water delivered per day to properties along the Inland Road/KEAR				
2016-11-29 1200	Inland Road/KEAR transferred back to NZTA, public access by application only	60% of Waiau rural scheme user tanks have had supply restored. Do not drink notice remains in place for Waiau rural scheme				
2016-11-30 1200		72% of Waiau rural scheme user tanks have had supply restored (66 restored, 16 outstanding, 9				

		unable to be contacted) Do not drink notice remains in place for Waiau rural scheme				
2016-12-1						Waiau sector post closed
2016-12-2		86% of Waiau rural scheme user tanks have had supply restored. Do not drink notice remains in place for Waiau rural scheme				
2016-12-5	Communication and processes for public use of Inland Road/KEAR					

	between farmers and contractors have broken down					
2016-12-6						Canterbury Declaration of Emergency expires
2016-12-9						National transition period begins